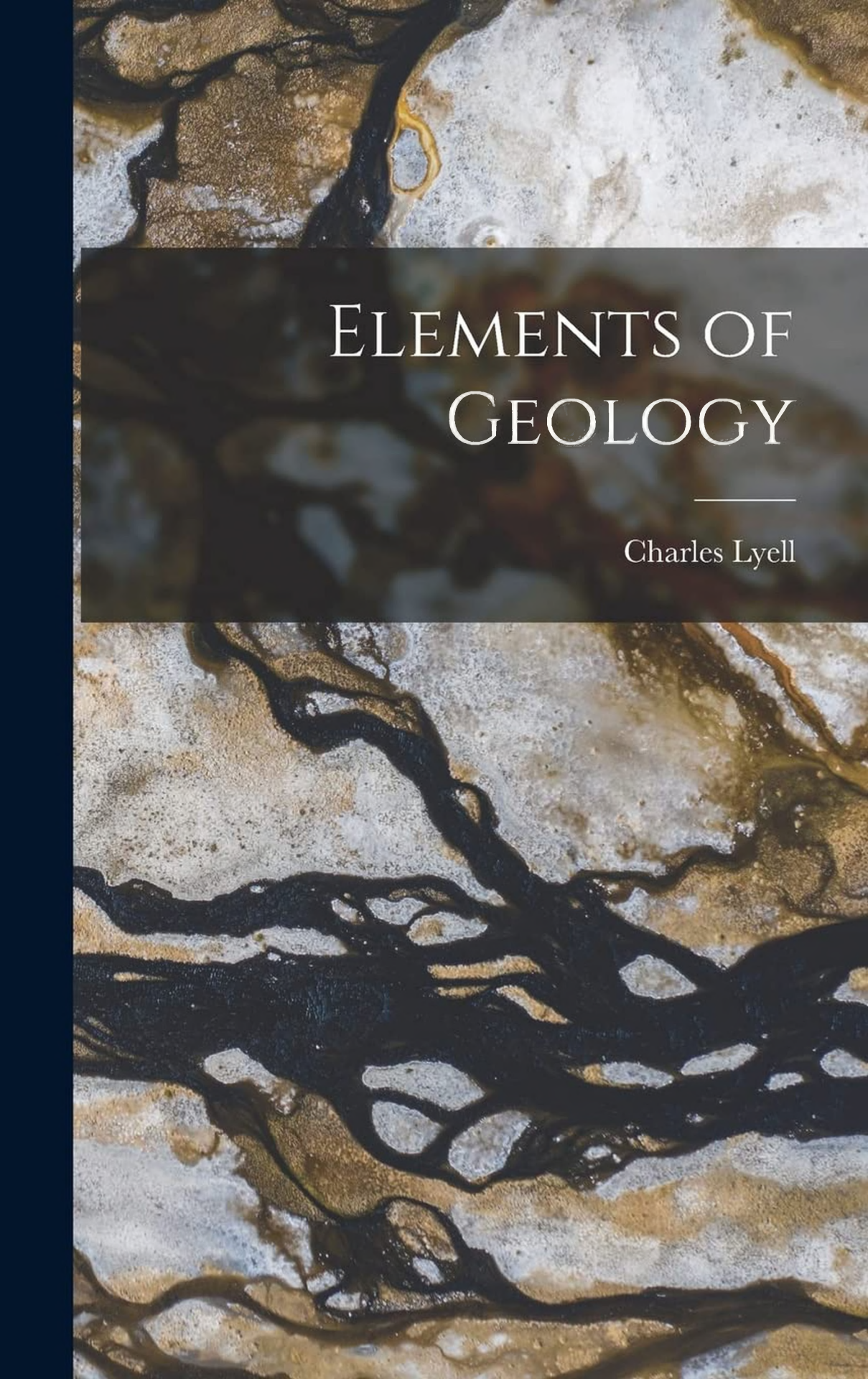


The book cover features a marbled pattern with swirling veins of black, brown, and tan on a light cream background. A dark, semi-transparent horizontal band runs across the middle, serving as a backdrop for the title and author's name.

ELEMENTS OF GEOLOGY

Charles Lyell

ELEMENTS
OF
GEOLOGY.
VOL. II.

ELEMENTS
OF
G E O L O G Y.

BY
CHARLES LYELL, ESQ., F. R. S.

VICE-PRESIDENT OF THE GEOLOGICAL SOCIETY OF LONDON, &C.;
AUTHOR OF "PRINCIPLES OF GEOLOGY."

"It is a philosophy which never rests,—its law is progress: a point which yesterday was invisible is its goal to-day, and will be its starting post to-morrow." — *EDIN. REV.*, No. 132. p. 83. July, 1837.

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ELEMENTS OF GEOLOGY.

CHAPTER XIX.

DENUDATION OF THE CHALK AND WEALDEN.

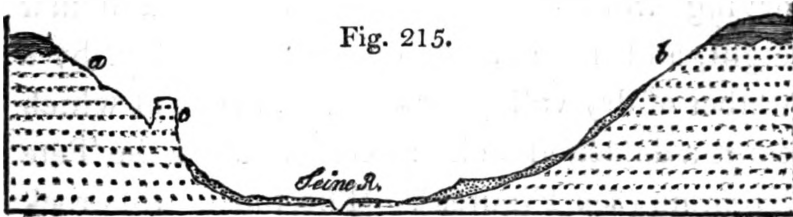
Physical geography of certain districts composed of Cretaceous and Wealden strata — Lines of inland chalk-cliffs on the Seine in Normandy — Outstanding pillars and needles of chalk — Denudation of the chalk and Wealden in Surrey, Kent, and Sussex — Chalk once continuous from the North to the South Downs — Anticlinal axis and parallel ridges — Longitudinal and transverse valleys — Chalk escarpments — Rise and denudation of the strata gradual — Ridges formed by harder, valleys by softer beds — Why no alluvium, or wreck of the chalk, in the central district of the Weald — At what period the Weald valley was denuded — Elephant bed, Brighton.

ALL the fossiliferous formations may be studied by the geologist in two distinct points of view ; first, in reference to their position in the series, their mineral character and fossils ; and, secondly, in regard to their physical geography, or the manner in which they now enter as mountain masses into the external structure of the earth.

Some account has already been given on the first head of the Cretaceous and Wealden strata, and we may now proceed to consider certain features in the physical geography of these groups as they occur in parts of England and France.

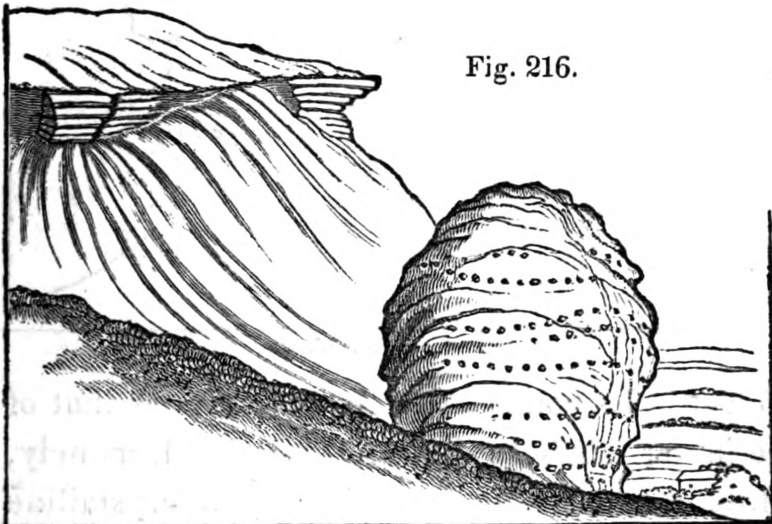
The hills composed of white chalk in the S. E. of England have a smooth rounded outline, and being usually in the state of sheep pastures, are free from trees or hedgerows ; so that we have an opportunity of observing how the valleys by which they are drained ramify in all directions, and become wider and deeper as they descend. Although these valleys are now for the most part dry, except during heavy rains and the melting of snow, they may have been due to aqueous denudation, as explained in the sixth chapter ; having been excavated when the chalk emerged gradually from the sea. This opinion is confirmed by the occasional occurrence of long lines of inland cliffs, in which the strata are cut off abruptly in a steep and often vertical precipice. The true nature of such escarpments is nowhere more obvious than in parts of Normandy, where the river Seine and its tributaries flow through deep winding valleys, hollowed out of chalk horizontally stratified. Thus, for example, if we follow the Seine for a distance of about 30 miles from Andelys to Elbœuf, we find the valley flanked on both sides by a steep slope of chalk, with numerous beds of

flint, the formation being laid open for a thickness of about 250 and 300 feet. Above the chalk is an overlying mass of tertiary sand, gravel, and clay, from 30 to 100 feet thick. The two opposite



Section across Valley of Seine.

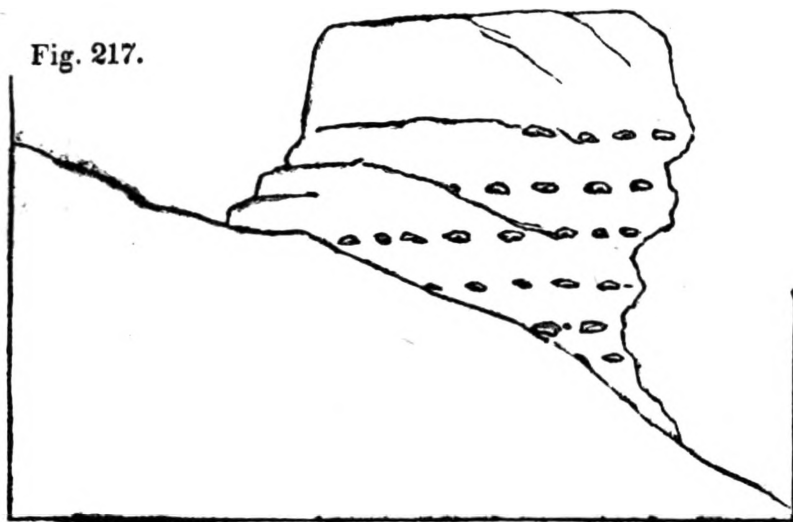
slopes of the hills *a* and *b*, where the chalk appears at the surface, are from two to four miles apart, and they are often perfectly smooth and even, like the steepest of our downs in England, but at many points they are broken by one, two, or more ranges of vertical, and even overhanging cliffs of bare white chalk with flints. At some



View of the Tête d'Homme, Anielys, seen from above.

points detached needles and pinnacles stand in the line of the cliffs, or in front of them as at *c* (Fig. 215). On the right bank of the Seine, at Andelys, one range about two miles long is seen, varying from 50 to 100 feet in perpendicular height, and having its continuity broken by a number of dry valleys or coombs, in one of which occurs a detached rock or needle, called the *Tête d'Homme* (see Figures). The top of this rock presents a precipitous face towards every point of the compass ; its vertical height being more than 20 feet on the side of the downs, and 40 towards the Seine, the average diameter of the pillar being

Fig. 217.



Side view of the Tête d'Homme.

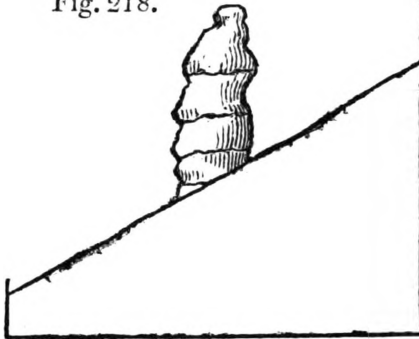
36 feet. Its composition is the same as that of the larger cliffs in its neighbourhood, namely, white chalk, having occasionally a crystalline texture like marble, with layers of flint in no-

dules and tabular masses. The flinty beds often project in relief four or five feet beyond the white chalk, which is generally in a state of slow decomposition, either exfoliating or being covered with white powder, like the chalk cliffs on the English coast ; and, as in them, this superficial powder contains in some places common salt.

Other cliffs are situated on the right bank of the Seine, opposite Tournedos, between Andelys and Pont de l'Arche, where the precipices are from 50 to 80 feet high : several of their summits terminate in pinnacles ; and one of them, in particular, is so completely detached as to present a perpendicular face 50 feet high towards the sloping down. On these cliffs several ledges are seen, which mark so many levels at which the waves of the sea may be supposed to have encroached for a long period. At a still greater height, immediately above the top of this range, are three much smaller cliffs, each about 4 feet high, with as many intervening terraces, which are continued so as to sweep in a semicircular form round an adjoining coomb, like those in Sicily before described (p. 155).

If we then descend the river from Vatteville to a place called Senneville, we meet with a singular needle about 50 feet high, perfectly isolated on the escarpment of chalk on the right bank of the Seine. (See Fig. 218.) Another conspicuous range

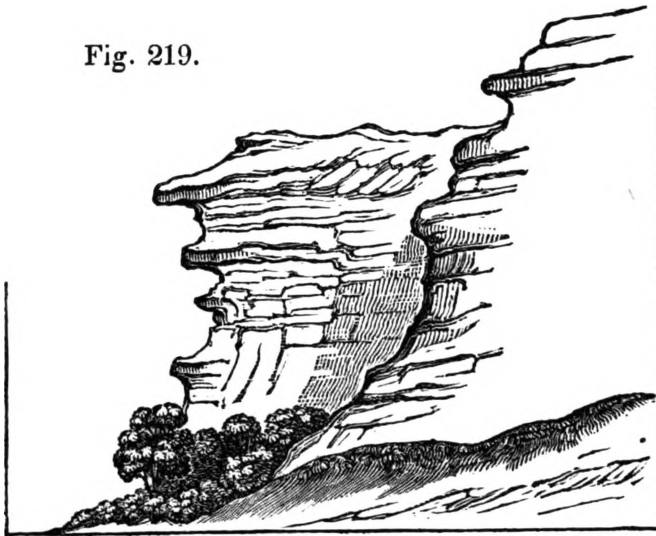
Fig. 218.

*Chalk pinnacle at Senneville.*

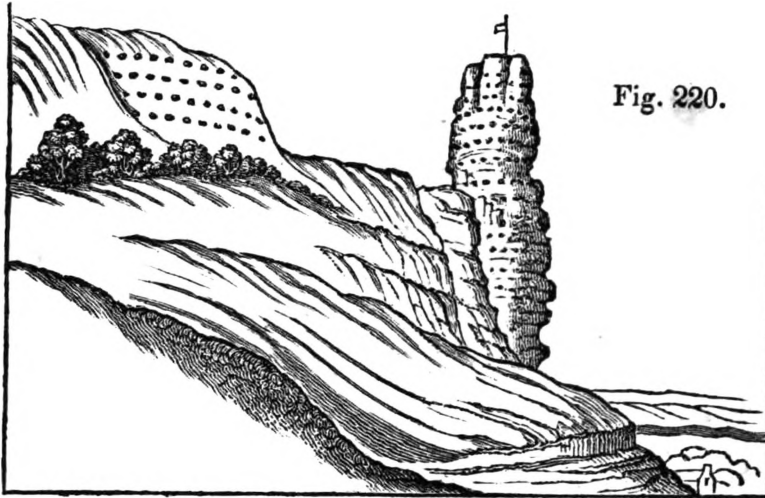
of inland cliffs is situated about twelve miles below, on the left bank of the Seine, beginning at Elbœuf, and comprehending the Roches d'Orival. (See Fig. 219.) Like

those before described, it has an irregular surface, often overhanging, and with beds of flint

Fig. 219.

*Roches d'Orival, Elbœuf.*

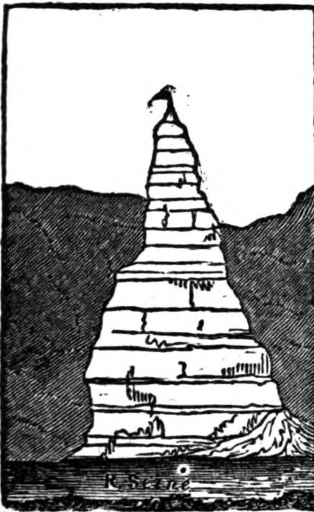
projecting several feet. Like them, also, it exhibits a white powdery surface, and consists entirely of horizontal chalk with flints. Although forty miles inland, its base is only a few feet above the level of the Seine; its height, in some parts, exceeding 200 feet. It is broken, in one place, by a pyramidal mass or needle,



View of the Roche de Pignon, seen from the south.

called the Roche de Pignon, which stands out

Fig. 221.



Roche de Pignon seen from the river.

about 25 feet in front of the upper portion of the main cliffs, with which it is united by a narrow ridge about 40 feet lower than its summit. (See Figures.) Its height is about 200 feet ; and, like the detached rocks before mentioned at Senneville, Vatteville, and Andelys, may be compared to those needles of chalk which

occur on the coast of Normandy, as well as in the Isle of Wight and in Purbeck.* (See Fig. 222.)

The foregoing description and drawings will

* An account of these cliffs was read by the author to the British Assoc. at Glasgow, Sept. 1840.

Fig. 222.



*Needle and Arch of Etretat, in the chalk cliffs of Normandy. Height of Arch, 100 feet. (Passy.)**

show that the evidence of certain escarpments of the chalk having been originally sea-cliffs, is far more full and satisfactory in France than in England. If it be asked why, in the interior of our own country, we meet with no ranges of precipices equally vertical and overhanging, and no isolated pillars or needles, we may reply that the greater hardness of the chalk in Normandy may, in some measure, be the cause of this difference. But the frequent absence of all signs of littoral denudation in the valley of the Seine itself is a negative fact of a far more striking and perplexing character. The cliffs, after being almost continuous for miles, are then wholly wanting for much greater distances, being replaced by a green sloping down, although the beds remain of the same composition, and are equally horizontal; and although we may feel assured that the manner of the upheaval of the

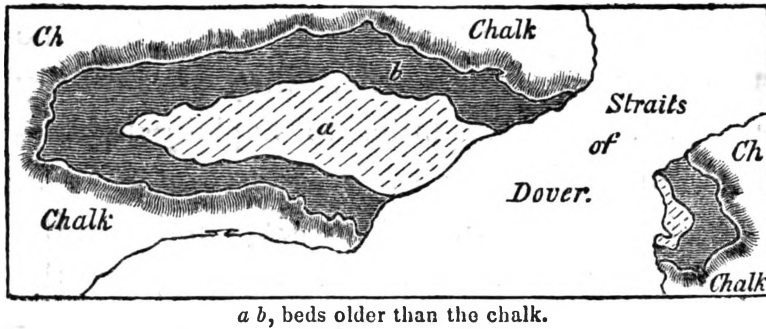
* Seine-Inferieure, p. 142. and pl. 6. fig. 1.



land, whether intermittent or not, must have been the same at those intermediate points where no cliffs exist, as at others where they are so fully developed. But, in order to explain such apparent anomalies, the reader must refer again to the theory of denudation, as expounded in the 6th Chapter ; where it was shown, first, that the undermining force of the waves and marine currents varies greatly at different parts of every coast; secondly, that precipitous rocks have often decomposed and crumbled down ; and thirdly, that many terraces and small cliffs may now lie concealed beneath a talus of detrital matter.

Denudation of the Weald Valley.—No district is better fitted to illustrate the manner in which a great series of strata may have been upheaved and gradually denuded than the country intervening between the North and South Downs. This region which is depicted in the accompanying map (from Mr. Greenough's large map of England,) is between 40 and 50 miles in breadth ; comprising within it the whole of Sussex, and parts of the counties of Kent, Surrey, and Hampshire. The space in which the formations older than the White Chalk, or those from the Gault to the Hastings sand inclusive, crop out, is bounded everywhere by a great escarpment of chalk, which is continued on the opposite side of the channel in the Bas Boulonnais in France, where it forms

Fig. 223.



a b, beds older than the chalk.

the semicircular boundary of a tract in which older strata also appear at the surface. (See Fig. 223.) The whole of this district may therefore be considered geologically as one and the same.

The five formations of the Weald Valley, indicated by different colors in the map, Plate 6., have been already described; and are, 1st, Chalk and Upper Green-sand; 2d, Gault, or blue calcareous marl; 3d, Lower Green-sand, consisting of greenish and ferruginous sands, with chert, and sometimes limestone; 4th, Weald Clay; 5th, Hastings Sands, composed chiefly of sand, clay, and sandstone.

The space inclosed within the escarpment of the chalk affords an example of what has been technically called a "valley of denudation;" where the strata, partially removed by aqueous excavation, dip away on all sides from a central axis. Thus, it is supposed that the area now occupied by the Hastings sands (No. 5.) was once covered by the Weald clay (No. 4.), and this again by the

Green-sand (No. 3.), and this by the Gault (No. 2.); and lastly, that the chalk (No. 1.) extended originally over the whole space between the North and the South Downs. This theory will be better understood by consulting the annexed diagram (Fig. 224.), where the dark lines represent what now remains, and the fainter ones those portions of rock which are believed to have been carried away.

At each end of the diagram the tertiary strata (*a*) are exhibited reposing on the chalk. In the middle are seen the Hastings sands (No. 5.), forming an anticlinal axis, on each side of which the other formations are arranged with an opposite dip. It has been necessary, however, in order to give a clear view of the different formations, to exaggerate the proportional height of each in comparison to its horizontal extent; and a true scale is therefore subjoined in another diagram (Fig. 225.), in order to correct the erroneous impression which might otherwise be made on the reader's mind. In this section the distance between the North and South Downs is represented to exceed forty miles; for the Valley of the Weald is here intersected in its longest diameter, in the direction of a line between Lewes and Maidstone.

Through the central portion, then, of the district supposed to be denuded runs a great anti-

Fig. 224.

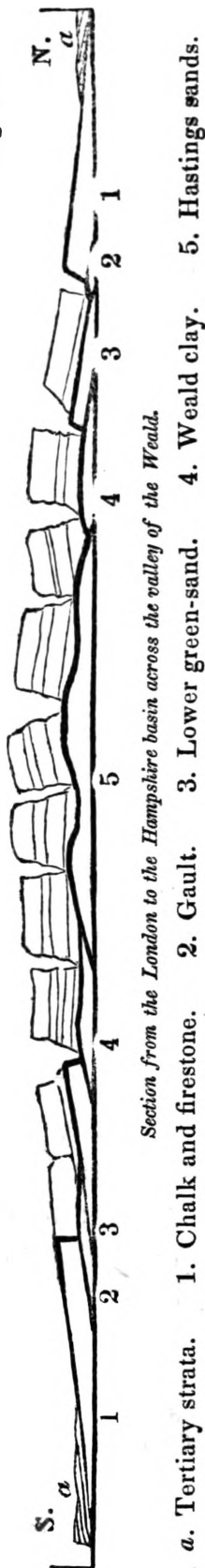
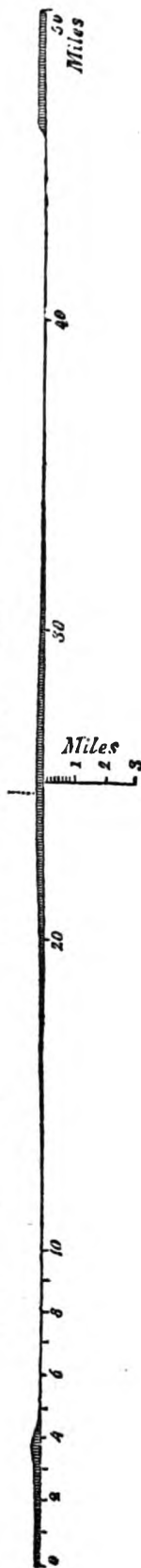


Fig. 225.

Highest point of North Downs, 880 feet.*

Anticlinal axis of the Weald.
Crowborough Hill, 804 feet.

Highest point of South Downs, 858 feet.



clinal line, having a direction nearly east and west, on both sides of which the beds 4, 3, 2, and 1, crop out in succession. But, although, for the sake of rendering the physical structure of this region more intelligible, the central line of elevation has alone been introduced, as in the diagrams of Smith, Mantell, Conybeare, and others, geologists have always been well aware that numerous minor lines of dislocation and flexure run parallel to the great central axis.

In the central area of the Hastings Sands, the strata have undergone the greatest displacement ; one fault being known, where the vertical shift of a bed of calcareous grit is no less than sixty fathoms.* Much of the picturesque scenery of this district arises from the depth of the narrow valleys and ridges to which the sharp bends and fractures of the strata have given rise ; but it is also in part to be attributed to the excavating power exerted by water, especially on the interstratified argillaceous beds.

Besides the series of longitudinal valleys and ridges in the Weald, there are valleys which run in a transverse direction, passing through the chalk to the basin of the Thames on the one side, and to the English channel on the other. In this manner the chain of the North Downs is broken by the rivers Wey, Mole, Darent,

* Fitton, Geol. of Hastings, p. 55.

Medway, and Stour; the South Downs by the Arun, Adur, Ouse, and Cuckmere.* If these transverse hollows could be filled up, all the rivers, observes Mr. Conybeare, would be forced to take an easterly course, and to empty themselves into the sea by Romney Marsh and Pevensey Levels.†

Mr. Martin has suggested that the great cross fractures of the chalk, which have become river channels, have a remarkable correspondence on each side of the valley of the Weald; in several instances the gorges in the North and South Downs appearing to be directly opposed to each other. Thus, for example, the defiles of the Wey in the North Downs, and of the Arun in the South, seem to coincide in direction; and, in like manner, the Ouse corresponds to the Darent, and the Cuckmere to the Medway.‡

Although these coincidences may, perhaps, be accidental, it is by no means improbable, as hinted by the author above mentioned, that the great amount of elevation towards the centre of the Weald district gave rise to transverse fissures. And as the longitudinal valleys were connected with that linear movement which caused the anticlinal lines running east and west, so the cross fissures might have been occasioned by the inten-

* Conybeare, *Outlines of Geol.*, p. 81. † *Ibid*, p. 145.

‡ *Geol. of Western Sussex*, p. 61.

sity of the upheaving force towards the centre of the line.

But before treating of the manner in which the upheaving movement may have acted, I shall endeavour to make the reader more intimately acquainted with the leading geographical features of the district, so far as they are of geological interest.

In whatever direction we travel from the tertiary strata of the basins of London and Hampshire (see Map, plate 6.) towards the valley of the Weald, we first ascend a slope of white chalk, with flints, and then find ourselves on the summit of a declivity consisting, for the most part, of different members of the chalk formation; below which the upper green-sand, and sometimes, also, the gault, crop out. This steep declivity is the great escarpment of the chalk before mentioned, which overhangs a valley excavated chiefly out of the argillaceous or marly bed, termed Gault (No. 2.). The escarpment is continuous along the southern termination of the North Downs, and may be traced from the sea, at Folkestone, westward to Guildford and the neighbourhood of Petersfield, and from thence to the termination of the South Downs at Beachy Head. In this precipice or steep slope the strata are cut off abruptly, and it is evident that they must originally have extended farther. In the accom-

Fig. 226.



View of the chalk escarpment of the South Downs. Taken from the Devil's Dike, looking towards the west and south-west.

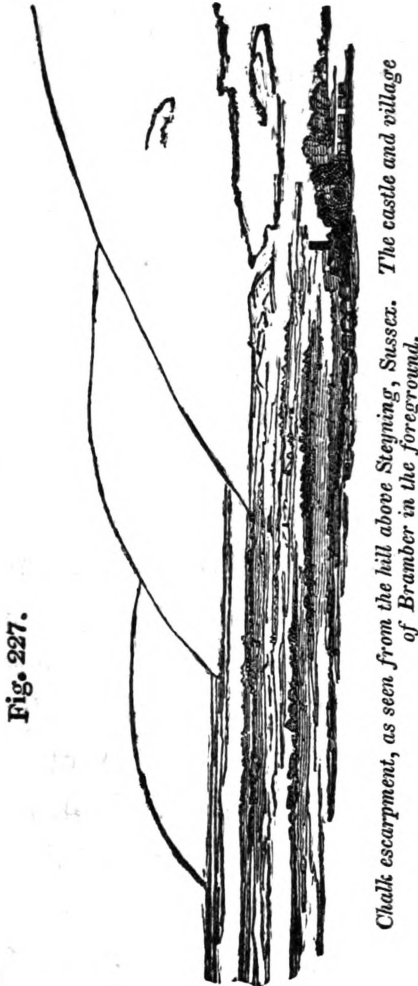
a. The town of Steyning is hidden by this point.

b. Edburton church.

c. Road.

d. River Adur.

panying wood-cut (Fig. 226.), part of the escarpment of the South Downs is faithfully represented, where the denudation at the base of the declivity



ity has been somewhat more extensive than usual, in consequence of the upper and lower green-sand being formed of very incoherent materials, the upper, indeed, being extremely thin and almost wanting.

The geologist cannot fail to recognize in this view the exact likeness of a sea-cliff; and if he turns and looks in an opposite direction, or east-

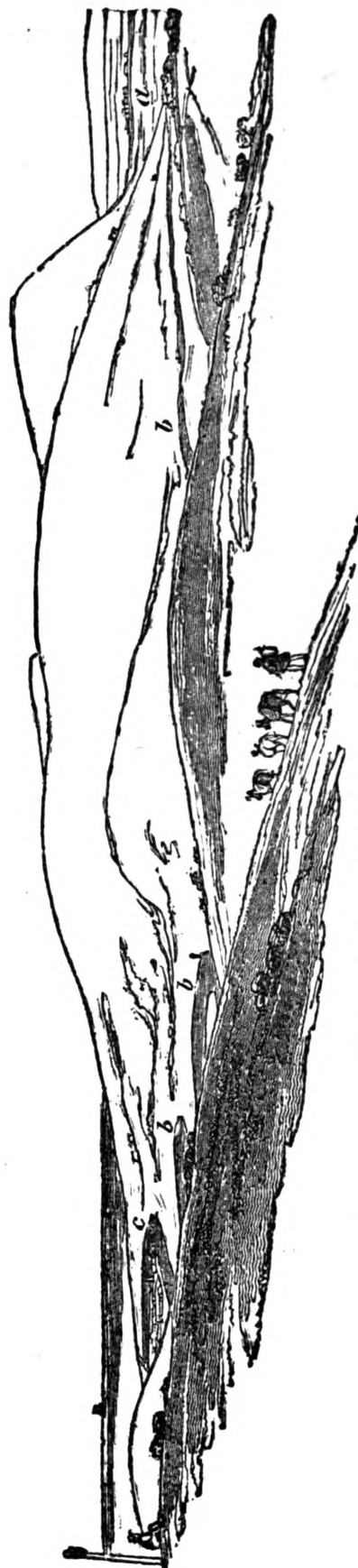
ward, towards Beachy Head (see Fig. 227.), he will see the same line of heights prolonged. Even those who are not accustomed to speculate on the former changes which the surface has undergone may fancy the broad and level plain to resemble the flat sands which were laid dry by the receding

tide, and the different projecting masses of chalk to be the headlands of a coast which separated the different bays from each other.

In regard to the transverse valleys before mentioned, as intersecting the chalk hills, some idea of them may be derived from the subjoined sketch (Fig. 228.) of the gorge of the river Adur, taken from the summit of the chalk downs, at a point in the bridle-way leading from the towns of Bramber and Steyning to Shoreham. If the reader will refer again to the view given in a former wood-cut (Fig. 226, p. 16.), he will there see the exact point where the gorge of which I am now speaking interrupts the chalk escarpment. A projecting hill, at the point *a*, hides the town of Steyning, near which the valley commences, where the Adur passes directly to the sea at Old Shoreham. The river flows through a nearly level plain, as do most of the others which intersect the hills of Surrey, Kent, and Sussex; and it is evident that these openings, so far at least as they are due to aqueous erosion, have not been produced by the rivers, many of which, like the Ouse near Lewes, have filled up arms of the sea, instead of deepening the hollows which they traverse.

Now, in order to account for the manner in which the five groups of strata, 1, 2, 3, 4, 5, represented in the Map, plate 6., and in the section Fig. 224., may have been brought into their

Fig. 228.



.Transverse Valley of the Adur in the South Downs.

Town of Steyning.

b. River Adur.

c. Old Shoreham.

present position, the following hypothesis has been very generally adopted : — Suppose the five formations to lie in horizontal stratification at the bottom of the sea ; then let a movement from below press them upwards into the form of a flattened dome, and let the crown of this dome be afterwards cut off, so that the incision should penetrate to the lowest of the five groups. The different beds would then be exposed on the surface, in the manner exhibited in the map, plate 6.*

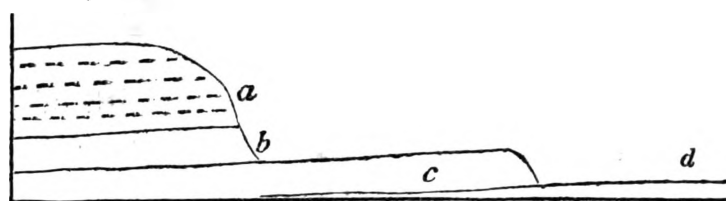
The quantity of denudation or removal by water of stratified masses assumed to have once reached continuously from the North to the South Downs is so enormous, that the reader may at first be startled by the boldness of the hypothesis. But the difficulty vanishes when once sufficient time is allowed for the gradual and successive rise of the strata, during which the waves and currents of the ocean might slowly accomplish an operation, which no sudden diluvial rush of waters could possibly have effected.

Among other proofs of the action of water, it may be stated that the great longitudinal valleys follow the outcrop of the softer and more incoherent beds, while ridges or lines of cliff usually occur at those points where the strata are com-

* See illustrations of this theory by Dr. Fitton, *Geol. Sketch of Hastings*.

posed of harder stone. Thus, for example, the chalk with flints, together with the subjacent upper green-sand, which is often used for building, under the provincial name of "firestone," has been cut into a steep cliff on that side on which the sea encroached. This escarpment bounds a deep valley, excavated chiefly out of the soft argillaceous or marly bed, termed gault (No. 2.). In some places the upper green-sand is in a loose and incoherent state, and there it has been as much denuded as the gault ; as, for example, near Beachy Head ; but farther to the westward it is of great thickness, and contains hard beds of blue chert and calcareous sandstone or firestone. Here, accordingly, we find that it produces a corresponding influence on the scenery of the country ; for it runs out like a step beyond the foot of the chalk-hills, and constitutes a lower terrace, varying in breadth from a quarter of a mile to three miles, and following the sinuosities of the chalk escarpment.*

Fig. 229.



a. Chalk with flints.

b. Chalk without flints.

c. Upper green-sand, or firestone. *d.* Gault.

* Mr. Murchison, *Geol. Sketch of Sussex, &c.*, *Geol. Trans.*, Second Series, vol. ii. p. 98.

It is impossible to desire a more satisfactory proof that the escarpment is due to the excavating power of water during the rise of the strata ; for I have shown, in my account of the coast of Sicily, in what manner the encroachments of the sea tend to efface that succession of terraces which must otherwise result from the intermittent upheaval of a coast preyed upon by the waves.* During the interval between two elevatory movements, the lower terrace will usually be destroyed wherever it is composed of incoherent materials ; whereas the sea will not have time entirely to sweep away another part of the same terrace, or lower platform, which happens to be composed of rocks of a harder texture, and capable of offering a firmer resistance to the erosive action of water. As the yielding clay termed gault would be readily washed away, we find its outcrop marked everywhere by a valley which skirts the base of the chalk hills, and which is usually bounded on the opposite side by the lower green-sand ; but as the upper beds of this last formation are most commonly loose and incoherent, they also have usually disappeared and increased the breadth of the valley. But in those districts where chert, limestone, and other solid materials enter largely into the composition of this formation (No. 3.), they

* See p. 153.

give rise to a range of hills parallel to the chalk, which sometimes rival the escarpment of the chalk itself in height, or even surpass it, as in Leith Hill, near Dorking. This ridge often presents a steep escarpment towards the soft argillaceous deposit called the Weald clay (No. 4; see the strong lines in Fig. 224. p. 12.), which usually forms a broad valley, separating the lower green-sand from the Hastings sands or Forest ridge; but where subordinate beds of sandstone of a firmer texture occur, the uniformity of the plain of No. 4. is broken by waving irregularities and hillocks.

It will be easy to show how closely these superficial inequalities agree with those which we might naturally expect to originate during the gradual rise of the Wealden district. Suppose the line of the most energetic movement to have coincided with what is now the central ridge of the Weald valley; in that case the first land which emerged must have been situated where the Forest ridge is now placed. Here many shoals and reefs may first have existed, and islands of chalk devoured in the course of ages by the ocean (see Fig. 225.); so that the top of the shattered dome which first appeared above water may have been utterly destroyed, and the masses represented by the fainter lines (Fig. 225.) removed.

The upper green-sand is represented as forming on the left hand a single precipice with the

chalk ; while on the right there are two cliffs, with an intervening terrace, as before described in

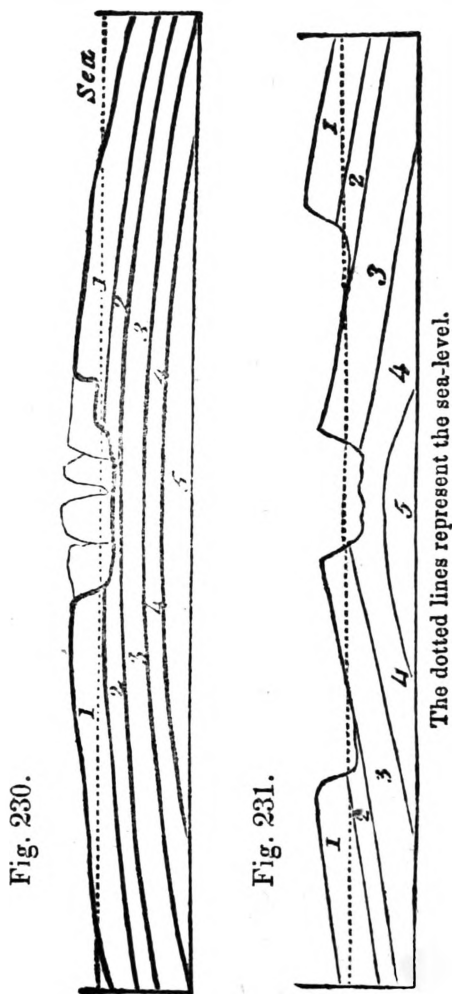


Fig. 229. p. 21. Two strips of land would then remain on each side of a channel ; in the same manner as the opposite coasts of France and England, composed of chalk, present ranges of white cliffs facing each other. A powerful current might then rush, like that which now ebbs

and flows through the Straits of Dover, and might scoop out a channel in the gault (No. 2.). This softer bed would yield with ease in proportion as parts of it were brought up from time to time and exposed to the fury of the waves, so that large spaces occupied by the harder formation or Green Sand (No. 3.) would be laid bare. This last rock opposing a more effectual resistance would next emerge; while the Chalk cliffs, at the base of which the gault is rapidly undermined, would recede farther from each other, after which four parallel strips of land, or rows of islands, would be caused, which are represented by the masses which in Fig. 231. rise above the dotted line indicating the sea-level. In this diagram, however, the inclination of the upper surface of the formations (Nos. 1. and 3.) is exaggerated. Originally this surface must have been level, like the submarine terraces produced by denudation, and described before (p. 149.); but they were afterwards more and more tilted by that general movement to which the region of the Weald owes its structure. At length, by the further elevation of the dome-shaped mass, the clay (No. 4.) would be brought within reach of the waves, which would probably gain the more easy access to the subjacent deposit by the rents which would be caused in No. 3., and in the central part of the ridge where the uplifting force had been exerted with the greatest energy. The opposite

cliffs, in which the Green Sand (No.3.) terminate, would now begin to recede from each other, having at their base a yielding stratum of clay (No. 4.). Lastly, the sea would penetrate to the sand (No. 5.), and then the state of things indicated in the dark lines of the upper section, Fig. 224., would be consummated.

It was stated that there are many lines of flexure and dislocation, running east and west, or

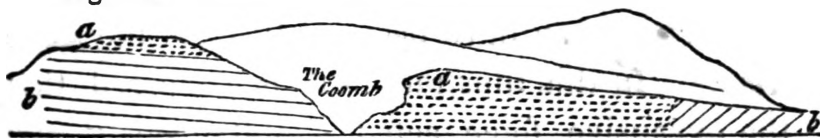
Fig. 232.



The Coomb, near Lewes.

parallel to the central axis of the Wealden. They are numerous in the district of the Hastings sand, and sometimes occur in the Chalk itself. One of the latter kind has given rise to the ravine called the Coomb, near Lewes, and was first traced out by Mr. Mantell, in whose company I examined it. This coomb is seen on the eastern side of the valley of the Ouse, in the suburbs of the town of Lewes. The steep declivities on each side are covered with green turf, as is the bottom, which is perfectly dry. No outward signs of disturbance are visible; and the connection of the hollow with subterranean movements would not have been suspected by the geologist, had not the evidence of great convulsions been clearly exposed in the escarpment of the valley of the Ouse, and the numerous chalk pits worked at the termination of the Coomb. By aid of these we discover that the ravine coincides precisely with a line of fault, on one side of which the chalk with flints (*a*), appears at the summit of the hill, while it is thrown down to the bottom on the other.

Fig. 233.

*Fault in the cliff-hills near Lewes. Mantell.**a.* Chalk with flints.*b.* Lower chalk.*

* For farther information, see Mantell's *Geol. of S. E. of England*, p. 352.

Mr. Martin, in his work on the geology of Western Sussex, published in 1828, threw much light on the structure of the Wealden by tracing out continuously for miles the direction of many anticlinal lines and cross fractures; and the same course of investigation has since been followed out in greater detail by Mr. Hopkins. The mathematician last mentioned has shown that the observed direction of the lines of flexure and dislocation in the Weald district coincide with those which might have been anticipated theoretically on mechanical principles, if we assume certain simple conditions under which the strata were lifted up by an expansive subterranean force. He finds by calculation that if this force was applied so as to act uniformly upwards within an elliptic area, the longitudinal fissures thereby produced would nearly coincide with the outlines of the ellipse, forming cracks, which are portions of smaller concentric ellipses, parallel to the margin of the larger one. These longitudinal fissures would also be intercepted by others running at right angles to them, and both lines of fracture may have been produced at the same time.* In this illustration it is supposed that the expansive force acted simultaneously and with equal intensity at every point within the upheaved area, and not with greater energy along the central axis or region of principal elevation.

* Geol. Soc. Proceedings, No, 74. p. 363. 1841.

The geologist cannot fail to derive great advantage in his speculations from the mathematical investigation of a problem of this kind, where results free from all uncertainty are obtained on the assumption of certain simple conditions. Such results when once ascertained by mathematical methods, may serve as standard cases, to which others occurring in nature of a more complicated kind may be referred. But in order that a uniform force should cause the strata to attain in the centre of the ellipse a height so far exceeding (especially before denudation) that which they have reached round the margin, it is necessary to assume that the mass of upheaved strata offered originally a very unequal degree of resistance to the subterranean force, either from being more fractured in one place than in another, or from being pressed down by a less weight of incumbent strata. It is suggested that they may have been acted upon somewhat in the manner of a carpet spread out loosely on a floor, and nailed down round the edges, which would swell into the shape of a dome if pressed up equally at every point by air admitted from beneath. But when we are reasoning on the particular phenomena of the Weald, we have no geological data for determining whether it be more probable that originally the resistance to be overcome was so extremely unequal in different places, or wheth-

er the subterranean force, instead of being everywhere uniform, was not applied with very different degrees of intensity beneath distinct portions of the upraised area.

The opinion that both the longitudinal and transverse lines of fracture may have been produced simultaneously, accords well with that expressed by M. Thurmann, in his work on the anticlinal ridges and valleys of elevation of the Bernese Jura.* For the accuracy of his map and sections I can vouch, from personal examination, in 1835, of part of the region surveyed by him. Among other results, at which this author arrived, it appears that the breadth of all the numerous anticlinal ridges and dome-shaped masses in the Jura is invariably great in proportion to the number of the formations exposed to view ; or, in other words, to the depth to which the superimposed groups of secondary strata have been laid open. (See Fig. 70. p. 118. for structure of Jura.) He also remarks, that the anticlinal lines are occasionally oblique and cross each other, in which case the greatest dislocation of the beds takes place. Some of the cross fractures are imagined by him to have been contemporaneous, others subsequent to the longitudinal ones.

I have assumed, in the former part of this chapter, that the rise of the Weald was gradual,

* *Soulèvements Jurassiques.* Paris, 1832.

whereas many geologists have attributed its elevation to a single effort of subterranean violence. There appears to them such a unity of effect in this and other lines of deranged strata in the south-east of England, such as that of the Isle of Wight, as is inconsistent with the supposition of a great number of separate movements recurring after long intervals of time. But we know that earthquakes are repeated throughout a long series of ages, in the same spots, like volcanic eruptions. The oldest lavas of Etna were poured out many thousands, perhaps myriads of years, before the newest, and yet they, and the movements accompanying their emission, have produced a symmetrical mountain; and if rivers of melted matter thus continue to flow in the same direction, and towards the same point, for an indefinite lapse of ages, what difficulty is there in conceiving that the subterranean volcanic force, occasioning the rise or fall of certain parts of the earth's crust, may, by reiterated movements, produce the most perfect unity of result?

Alluvium of the Weald.—Our next inquiry may be directed to the alluvium strewed over the surface of the supposed area of denudation. Has any wreck been left behind of the strata removed? To this we may answer, 1st, that the summit of the chalk downs are covered everywhere with gravel composed of partially rounded chalk flints,

such as might remain after masses of white chalk had been softened and removed by the sea, the harder materials of the siliceous strata not being carried away. But it is remarkable, that similar gravel is usually wanting in the deep longitudinal valleys at the foot of the chalk escarpment, although, in some few instances, the detritus of the chalk has been traced in patches over the gault, and even the lower green-sand, for a distance of several miles from the escarpment of the north and south downs. But no vestige of the chalk and its flints have been seen on the central ridge of the Weald or the Hastings sands, but merely gravel derived from the rocks immediately subjacent. This distribution of alluvium, and especially the absence of chalk detritus in the central district, agrees well with the theory of denudation before set forth ; for, to return to Fig.230., if the chalk (No.1.) were once continuous and covered everywhere with flint gravel, this superficial covering would be the first to be carried away from the highest part of the dome long before any of the gault (No. 2.) was laid bare. Now if some ruins of the chalk remain at first on the gault, these would be, in a great degree, cleared away before any part of the lower green-sand (No. 3.) is denuded. Thus in proportion to the number and thickness of the groups removed in succession, is

the probability lessened of our finding any remnants of the highest group strewn over the bared surface of the lowest.

As an exception to the general rule of the small distance to which any wreck of the chalk can be traced from the escarpments of the North and South Downs, I may mention a thick bed of chalk flints which occurs near Barcombe, about three miles to the north of Lewes (see Fig. 234.), a

Fig. 234.



Section from the North escarpment of the South Downs to Barcombe.

1. Gravel composed of partially rounded chalk flints.
2. Chalk with and without flints.
3. Lowest chalk or chalk marl (upper green-sand wanting).
4. Gault.
5. Lower green-sand.
6. Weald clay.

place which I visited with Mr. Mantell, to whom I am indebted for the accompanying section. Even here it will be seen that the gravel reaches no farther than the Weald Clay. The same section shows one of the minor east and west anticlinal lines before alluded to (p. 13.).

At what period the Weald Valley was denuded.

— If we inquire at what geological period the denudation of the Weald was effected, we shall immediately perceive that the question is limited to this point, whether it took place during or subsequent to the deposition of the Eocene strata of the south of England. For in the basins of London and Hampshire the Eocene strata are conformable to the chalk, being horizontal where the beds of chalk are horizontal, and vertical where they are vertical, so that both series of rocks appear to have participated in nearly the same movements. At the eastern extremity of the Isle of Wight some beds even of the fresh-water series, have been thrown on their edges, like those of the London clay. Nevertheless we can by no means infer that the tertiary deposits of the London and Hampshire basins once extended like the chalk over the entire valley of the Weald, because the denudation of the chalk and green-sand may have been going on in the centre of that area, while contiguous parts of the sea were sufficiently deep

to receive and retain the matter derived from that waste.

Thus while the waves and currents were excavating the longitudinal valleys D and C (Fig. 235.), the deposits *a* may have been thrown

Fig. 235.



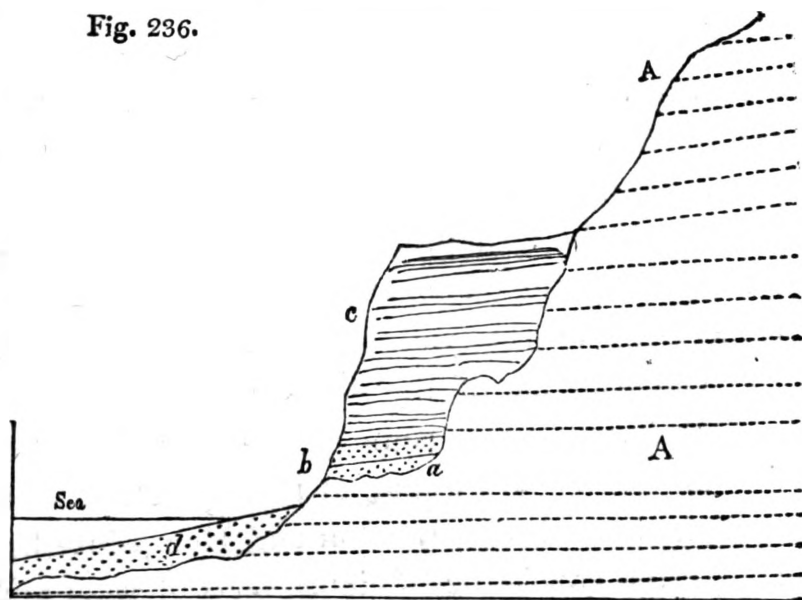
down to the bottom of the contiguous deep water E, the sediment being drifted through transverse fissures, as before explained. In this case, the rise of the formations Nos. 1, 2, 3, 4, 5, may have been going on contemporaneously with the excavation of the valleys C and D, and with the accumulation of the strata *a*.

This idea receives some countenance from the fact of the tertiary strata, at their junction with the chalk and the London and Hampshire basins, often consisting of dense beds of sand and shingle, as the Addington Hills near Croydon. They also contain occasionally fresh-water shells and the remains of land animals and plants, which indicate the former presence of land at no great distance, some part of which may have occupied the centre of the Weald.

Nevertheless, a great portion of the upheaval and denudation of the south-eastern part of Eng-

land was certainly posterior in date to the deposition of the London clay, because patches of that formation reach to a great height on the chalk. But it would lead me into too wide a digression were I fully to discuss this question at present; and I must refer to what I have said when treating of mountain-chains in the Principles of Geology, to show how difficult is the

Fig. 236.



- A. Chalk with layers of flint dipping slightly to the south.
- b. Ancient beach, consisting of fine sand, from one to four feet thick, covered by shingle from five to eight feet thick of pebbles of chalk-flint, granite, and other rocks, with broken shells, &c.
- c. Elephant bed, about fifty feet thick, consisting of layers of white chalk rubble, with broken chalk flints, in which deposit are found bones of ox, deer, horse, and mammoth.
- d. Sand and shingle of modern beach.

determination of the relative dates of the disturbance of strata. Eocene deposits may have been uplifted to great heights before the close of the Eocene period, or before the living species of that era had passed away from the earth.

We may, however, affirm with confidence, that considerable movements of elevation have been experienced in the south-east of England, at periods decidedly post-Eocene ; as, for example, those by which the Crag strata attained their present position above the sea in Norfolk, Suffolk, and Essex. The formation also called by Mr. Mantell the Elephant Bed, at the foot of the chalk cliffs at Brighton, is not merely a talus of calcareous rubble collected at the base of an inland cliff, but exhibits every appearance of having been spread out in successive horizontal layers by water in motion.

The deposit alluded to skirts the shores between Brighton and Rottingdean, and another mass apparently of the same age occurs at Dover. The phenomena appear to me to suggest the following conclusions : — First, the south-eastern part of England had acquired its actual configuration when the ancient chalk cliff *A a* was formed, the beach of sand and shingle *b* having then been thrown up at the base of the cliff. Afterwards the whole coast, or at least that part of it where the elephant bed now ex-

tends, subsided to the depth of fifty or sixty feet : and during the period of submergence successive layers of white calcareous rubble *c* were accumulated, so as to cover the ancient beach *b*. Subsequently, the coast was again raised, so that the ancient shore was elevated to a level somewhat higher than its original position.*

* See Mantell's Geol. of S. E. of England, p. 32. After re-examining the elephant bed in 1834, I was no longer in doubt of its having been a regular subaqueous deposit.

CHAPTER. XX.

OOLITE AND LIAS.

Subdivisions of the Oolitic groups — Fossil shells — Corals in the calcareous divisions only — Buried forest of Encrinurites in Bradford clay — Changes in organic life — Characteristic fossils — Signs of neighbouring land and shoals — Supposed cetacea in Oolite — Oolite of Yorkshire and Scotland.

OOLITE. — Below the fresh-water group called the Wealden, or, where this is wanting, immediately beneath the Cretaceous formation, a great series of marine strata, commonly called “the Oolite,” occurs in many parts of Europe. This group has been so named, because, in England and other places where it was first examined, the limestones belonging to it had an oolitic structure (see p. 26.). These rocks occupy in England a zone which is nearly thirty miles in average breadth, and extends across the island, from Yorkshire on the north-east, to Dorsetshire on the south-west.* Their mineral characters are not uniform throughout this region; but the follow-

* For details respecting this formation in England, see Conybeare and Phillips’s *Geology*, chap. iii.

ing are the names of the principal subdivisions observed in the central and south-eastern parts of England : —

OOLITE.

Upper	{	<i>a.</i> Portland stone and sand.
		<i>b.</i> Kimmeridge clay.
Middle	{	<i>c.</i> Coral rag.
		<i>d.</i> Oxford clay.
Lower	{	<i>e.</i> Cornbrash and Forest Marble.
		<i>f.</i> Great Oolite and Stonesfield slate.
		<i>g.</i> Fuller's earth.
		<i>h.</i> Inferior Oolite.

The Lias then succeeds to the Inferior Oolite.

The upper oolitic system of the above Table has usually the Kimmeridge clay for its base, and the middle oolitic system the Oxford clay. The lower system reposes on the Lias, an argillolocalcareous formation, which some include in the lower oolite, but which will be treated of separately in the next chapter. Many of these subdivisions are distinguished by peculiar organic remains; and though varying in thickness, may be traced in certain directions for great distances, especially if we compare the part of England to which the above-mentioned type refers with the north-west of France, and the Jura mountains, which separate that country from Switzerland, and in which, though distant above 400 geographical miles, the analogy to the English type above mentioned is more perfect than in Yorkshire or Normandy.

To enter upon a systematic description of this complicated series of strata would require many chapters; the following facts, therefore, are selected from a multitude of others, with a view of illustrating the origin of the oolitic rocks, and of showing the state of organic life and geographical condition of part of the globe when they were formed.

In almost all the minor divisions enumerated in the above Table, *Ammonites* and *Belemnites* are found (see Figs. 253. 255.), but of species different from those of the cretaceous period. The *ammonites* are of various sizes, from the size of a small carriage-wheel to less than an inch diameter.

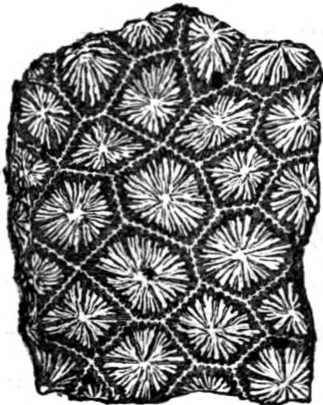
It is not uncommon to find *belemnites* in different members of the series, with full-grown *serpulæ* attached to them. As these shells, like the bone of the cuttle-fish, so often thrown on our shores, were internal, it is clear that after the death of the cephalopod the *belemnite* remained for some time unburied at the bottom of the sea, so that the *serpulæ* grew upon it.

These cephalopoda, swimming about in the open sea, left their shells to be imbedded indifferently in whatever sediment was then in the course of deposition, whether calareous or argillaceous. But the corals are almost entirely confined to the limestones, and are wanting in the dense formations of interposed clay, as also in the Lias,

these zoophytes requiring not only carbonate of lime for their support, and clear water, but a bottom remaining for years unchanged, either by the shifting of sand or the accession of fresh sediment.

In the Upper Oolite of England, corals are rare, although one species is found plentifully at Tisbury, in Wiltshire, in the Portland sand converted into flint and chert, the original calcareous matter being replaced by silex. (Fig. 237.) One of the limestones of the Middle Oolite has been called the "Coral Rag," because it consists, in part, of continuous beds of petrified corals, for the most part retaining the position in which they grew at the bottom of the sea. They belong chiefly to the genera *Caryophyllia* (Fig. 238.), *Agaricia*, and

Fig. 237.



Columnaria oblonga, Blainv.
Upper Oolite, Tisbury.

Fig. 238.



Caryophyllia annularis, Parkin.
Coral rag, Steeple Ashton.

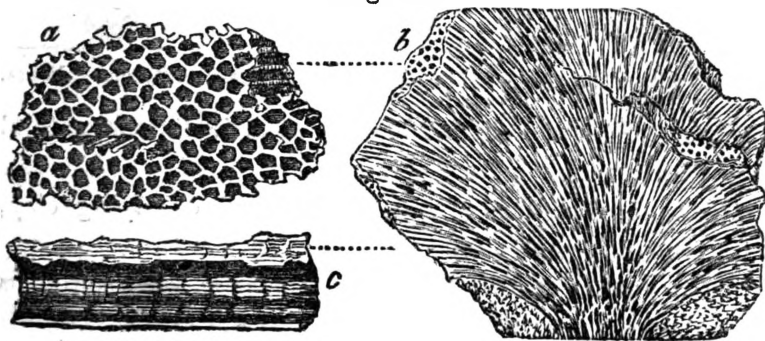
Astrea, and sometimes form masses of coral fifteen feet thick. In the annexed figure of an *Astrea*,

Fig. 239.

*Astrea*; Coral Rag.

from this formation, it will be seen that the cup-shaped cavities are deepest on the right-hand side, and that they grow more and more shallow, till those on the left side are nearly filled up. The last-named stars are supposed to be *Polyparia* of advanced age. These coralline strata extend through the calcareous hills of the N.W. of Berkshire, and north of Wilts, and again recur in Yorkshire, near Scarborough. Although the name of coral rag has been thus appropriated, there are portions of the lower oolite, as for example, the Great and Inferior Oolite (*f. h.* Table, p. 40.), which are equally intitled in many places to be called coralline limestones. Thus the Great Oolite near Bath contains various corals, among which the

Fig. 240.

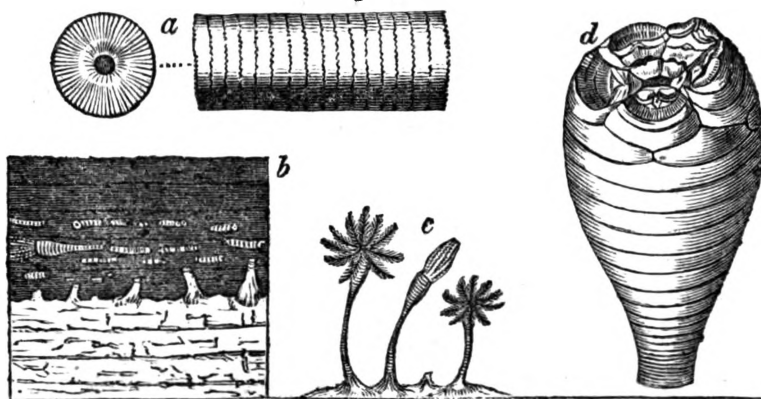
*Eunomia radiata*, Lamouroux.

- a.* section transverse to the tubes.
- b.* vertical section, showing the radiation of the tubes.
- c.* portion of interior of tubes magnified, showing striated surface.

Eunomia radiata (Fig. 240.) is very conspicuous, single individuals forming masses several feet in diameter ; and having probably required, like the large existing brain-coral (*Meandrina*) of the tropics, many centuries before their growth was completed.

Different species of *Crinoideans*, or stone-lilies, are also common in the same rocks with corals ; and, like them, must have enjoyed a firm bottom, where their root, or base of attachment, remained undisturbed for years (c. Fig. 241.). Such fossils,

Fig. 241.



Apiocrinites rotundus, or *Pear Encrinite* ; Miller. Fossil at Bradford, Wilts.

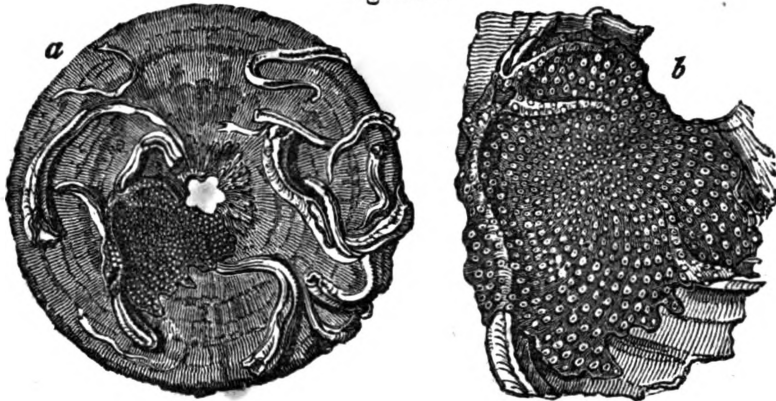
- a. Stem of *Apiocrinites*, and one of the articulations, natural size.
- b. Section at Bradford of great oolite and overlying clay, containing the fossil encrinites. See text.
- c. Three perfect individuals of *Apiocrinites*, represented as they grew on the surface of the Great Oolite.
- d. Body of the *Apiocrinites rotundus*.

therefore, are almost confined to the limestones ; but an exception occurs at Bradford, near Bath, where they are enveloped in clay. In this case,

however, it appears that the solid upper surface of the "Great Oolite" had supported, for a time, a thick submarine forest of these beautiful zoophytes, until the clear and still water was invaded by a current charged with mud, which threw down the stone-lilies, and broke most of their stems short off near the point of attachment. The stumps still remain in their original position ; but the numerous articulations once composing the stem, arms, and body of the zoophyte, were scattered at random through the argillaceous deposit in which some of them now lie prostrate. These appearances are represented in the section *b*, Fig. 241., where the darker strata represent the Bradford clay, a member of the Forest marble (*e.* Table, p. 40.). The upper surface of the calcareous stone below is completely incrustated over with a continuous pavement, formed by the stony roots or attachments of the Crinoidea ; and besides this evidence of the length of time they had lived on the spot, we find great numbers of single joints, or circular plates of the stem and body of the encrinite, covered over with *serpulæ*. Now these *serpulæ* could only have begun to grow after the death of some of the stone-lilies, parts of whose skeletons had been strewn over the floor of the ocean before the irruption of argillaceous mud. In some instances we find that, after the parasitic *serpulæ* were full grown, they had become incrustated over with a coral, called *Berenicea*

diluviana; and many generations of these polyps had succeeded each other in the pure water before they became fossil.

Fig. 242.



- a. Single plate, or articulation of an Encrinurite overgrown with *serpulae* and corals. Natural size. Bradford clay.
- b. Portion of the same magnified, showing the coral *Berenicea diluviana* covering one of the *serpulae*.

We may, therefore, perceive distinctly that, as the pines and cycadeous plants of the ancient Portland Forest were killed by submergence under fresh water, and soon buried beneath muddy sediment, so an invasion of argillaceous matter put a sudden stop to the growth of the Bradford Encrinurites, and led to their preservation in marine strata.*

Such differences in the fossils as distinguish the calcareous and argillaceous deposits from each other, would be described by naturalists as arising out of a difference in the *stations* of species; but

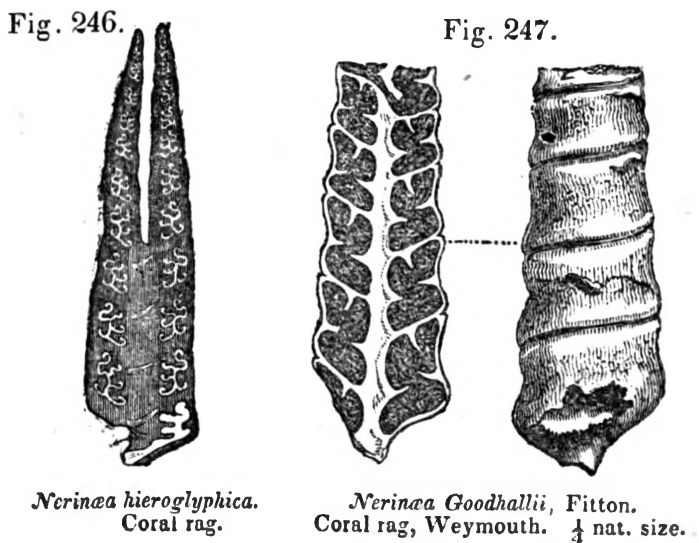
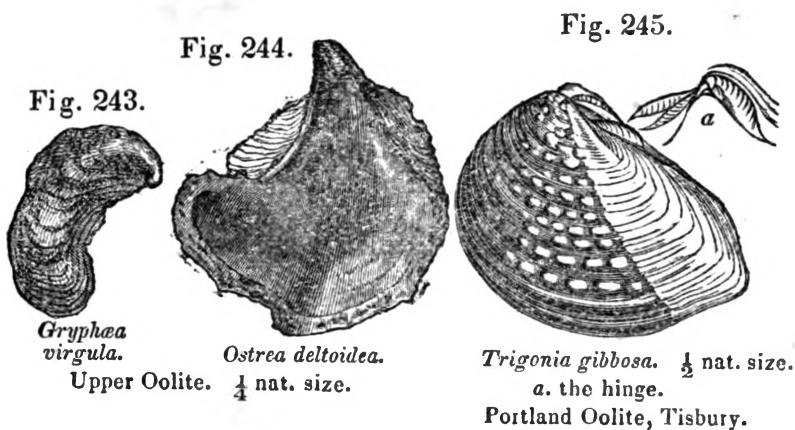
* For a fuller account of these Encrinurites, see Buckland's *Bridgewater Treatise*, vol. i. p. 429.

besides these, there are variations in the fossils of the higher, middle, and lower part of the oolitic series, which must be ascribed to that great law of change in organic life by which distinct assemblages of species have been adapted, at successive geological periods, to the varying conditions of the habitable surface. In a single district it is difficult to decide how far the limitation of species to certain minor formations has been due to the local influence of *stations*, or how far it has been caused by time, or the creative and destroying law above alluded to. But we recognize the reality of the last-mentioned influence, when we contrast the whole oolitic series of England with that of parts of the Jura, Alps, and other distant regions, where there is scarcely any lithological resemblance; and yet some of the same fossils remain peculiar in each country to the Upper, Middle, and Lower Oolite formations respectively. Mr. Thurmann has shown how remarkably this fact holds true in the Bernese Jura, although the argillaceous divisions, so conspicuous in England, are feebly represented there, and some entirely wanting.

Amongst the characteristic fossils of the Upper Oolite, may be mentioned the *Ostrea deltoidea* (Fig. 244.), found in the Kimmeridge clay throughout England and the north of France, and also in Scotland, near Brora. The *Gryphæa*

virgula (Fig. 243.), also met with in the same clay near Oxford, and so abundant in the upper oolite of parts of France as to have caused the deposit to be termed "marnes à gryphées virgules." Near Clermont, in Argonne, a few leagues from St. Menehould, these indurated marls crop out from beneath the gault; and, on decompos-

FOSSILS OF THE OOLITE.



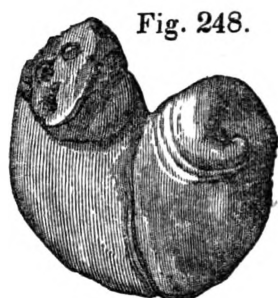


Fig. 248.
Cast of *Diceras arictina*.
Coral rag.



Fig. 249.
Cidaris coronata.
Coral rag.

ing, leave the surface of every ploughed field literally strewed over with fossil oysters.

One of the limestones of the Jura, referred to the age of the English coral rag, has been called "Nerinéan limestone" (Calcaire à Nérinées) by M. Thirria; *Nerinaea* being an extinct genus of univalve shells, much resembling the *Cerithium* in external form, and peculiar to the Oolitic period. The annexed section (Fig. 246.) shows the curious form of the hollow part of each whorl, and also the perforation which passes up the middle of the columella. *N. Goodhallii* (Fig. 247.) is another English species of the same genus, from a formation which seems to form a passage from the Kimmeridge clay to the coral rag.*

A division of the oolite in the Alps, regarded by most geologists as coeval with the English coral

* Fitton, Geol. Trans., Second Series, vol. iv. pl. 23. fig. 12.

rag, has been often named "Calcaire à Dicera-tes," or "Diceras limestone," from its contain-
ing abundantly a bivalve shell (see Fig. 248.)
of a genus allied to the *Chama*.

Among the characteristic shells of the Inferior
Oolite, I may instance *Terebratula spinosa* (Fig.
251.), *Pholadomya fidicula* (Fig. 252.), *Belem-*

Fig. 250.



Pleurotomaria ornata.
Ferruginous oolite, Nor-
mandy. Inf. ool., Eng-
land.

nites hastatus (Fig. 253.), and
Terabratula digona (Fig.
256.). The extinct genus
Pleurotomaria is also a form
very common in the Oolitic
system. It resembles the *Tro-*
chus in form, but is marked
by a singular cleft (*a*, Fig.
250.) on the right side of the mouth.

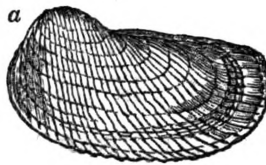
As illustrations of shells having a great vertical
range, I may allude to *Trigonia gibbosa* (Fig.
245.), which abounds in the Portland stone of

Fig. 251.



Terebratula spinosa.
Inferior Oolite.

Fig. 252.



a. Pholadomya fidicula. $\frac{1}{3}$ nat. size. Inf. Ool.
b. Heart-shaped anterior termination of the same.

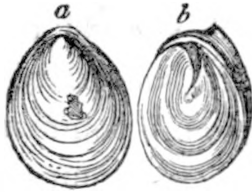


Fig. 253.



Belemnites hastatus. Inferior Oolite.

Fig. 254.

*Orbicula reflexa*, Sow.

a. upper valve.
b. lower or attached valve, and
showing part of the upper.

Fig. 256.

*Terebratula digona*.

Lower Oolite, Bradford. Nat. size.

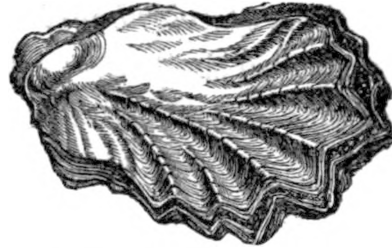
Fig. 255.

*Ammonites striatulus*, Sow.

$\frac{1}{3}$ nat. size.

Inferior Oolite and Lias.

Fig. 257.

*Ostrea Marshii*. $\frac{1}{3}$ nat. size.

Middle and Lower Oolite.

Wiltshire, and the Inferior Oolite of Yorkshire.*
Trigonia clavellata also has the same range, and
T. costata is common to the Upper, Middle, and
Lower Oolite. Also *Ostrea Marshii* (Fig. 257.),
common to the Cornbrash of Wilts and the In-
ferior Oolite of Yorkshire; and, lastly, *Orbicula*
reflexa (Fig. 254.) and *Ammonites striatulus*
(Fig. 255.), fossils common to the Inferior
Oolite and Lias.

Such facts by no means invalidate the general
rule, that certain fossils are good chronological
tests of geological periods; but they serve to

* See Williamson, Proceedings Geol. Soc., No. 47.

caution us against attaching too much importance to single species, some of which may have a wider, others a more confined vertical range. We have before seen that, in the successive tertiary formations, there are species common to older and newer groups, yet these groups may be distinguishable from one another by a comparison of the whole assemblage of fossil shells proper to each.

Signs of neighbouring land and shoals.—The corals and shells above alluded to, and the fishes, crustacea, and other accompanying fossils, sufficiently attest the marine origin of the oolitic strata in general. Yet there are frequent signs of shallow water and of neighbouring land: and these are the more worthy of attention, as they by no means diminish as we proceed downwards to the inferior parts of the oolitic series. Had the bottom of the sea in Europe been unmoved during the entire Oolitic period, the first, or oldest beds of the oolite, must have been accumulated in the deepest water, the middle oolite in water of less depth, and the upper in the shallowest of all. The appearances about to be described militate against this conclusion. Fossil wood occurs in the Upper Oolite, showing that there were then lands from which plants were drifted into the sea. The Kimmeridge clay, a member of the Upper Oolite, consists, in great part, of a bituminous shale,

sometimes forming an impure coal several hundred feet in thickness. In some places in Wiltshire it much resembles peat ; and the bituminous matter may have been, in part at least, derived from the decomposition of vegetables. But as impressions of plants are rare in these shales, which contain ammonites, oysters, and other marine shells, the bitumen may perhaps be of animal origin.

The celebrated lithographic stone of Solenhofen, in Bavaria, belongs to one of the upper divisions of the oolite, and affords a remarkable example of the variety of fossils which may be preserved under favourable circumstances, and what delicate impressions of the tender parts of certain animals and plants may be retained where the sediment is of extreme fineness. Although the number of testacea in this slate is small, and the plants few, and those all marine, Count Munster had determined no less than 237 species of fossils when I saw his collection in 1833 ; and among them no less than seven *species* of flying lizards, or pterodactyls, six saurians, three tortoises, sixty species of fish, forty-six of crustacea, and twenty-six of insects. These insects, among which is a libellula, or dragon-fly, must have been blown out to sea, probably from the same land to which the flying lizards, and other contemporaneous reptiles, resorted.

In the upper members of the *Lower Oolite* of England the ripple-mark is distinctly seen throughout a considerable thickness of thin fissile beds of a coarsely oolitic limestone. The rippled slabs are used for roofing, and have been traced over a broad band of country from Bradford, in Wilts, to Tetbury, in Gloucestershire. These calcareous slabs, or tile-stones, are separated from each other by thin seams of clay, which have been deposited upon them, and have taken their form, preserving the undulating ridges and furrows of the sand in such complete integrity, that the impressions of small footsteps, apparently of crabs, which walked over the soft wet sands, are still visible. In the same stone the claws of crabs, fragments of echini, broken shells, pieces of drift wood, and other signs of a neighbouring beach, are observed.

The slate of Stonesfield has lately been shown by Mr. Lonsdale to lie at the base of the Great Oolite.* It is a slightly oolitic shelly limestone, forming large spheroidal masses imbedded in sand, only six feet thick, but very rich in organic remains. It contains some pebbles of a rock very similar to itself, and with them the fossil remains of belemnites, trigoniæ, and other marine shells. Besides fragments of wood, which occur in all parts of the oolitic group, there are many

* Proceedings Geol. Soc. vol. i. p. 414.

impressions of ferns, cycadeæ, and other terrestri-

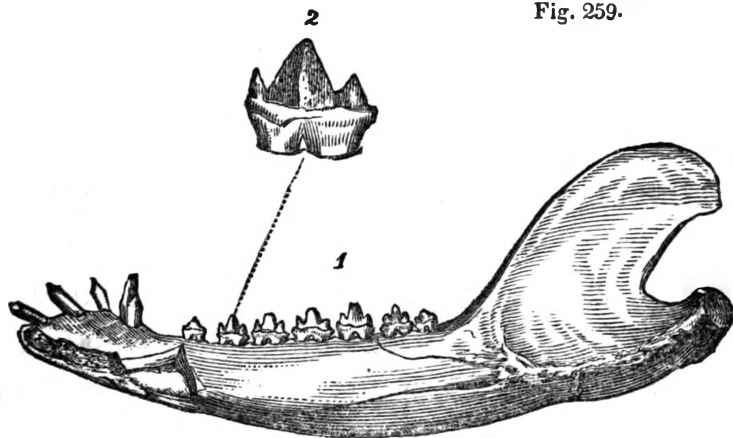
al plants. Several insects also, and, among the rest, the wing-covers of beetles, are perfectly preserved (see Fig. 258.), some of them approaching nearly to the genus *Buprestis*.* The remains, also, of many genera of reptiles, such as *Plesiosaurus*, *Crocodile*, and *Pterodactyl*, have been discovered in the same



*Elytron of
Buprestis;
Stonesfield.*

limestone; and, what is still more remarkable, the jaws of at least two species of mammiferous quadrupeds, of the Marsupial order; one allied to the *Didelphys*, or opossum, and the other to the *Myrmecobius* of Australia (see Figures).

Fig. 259.



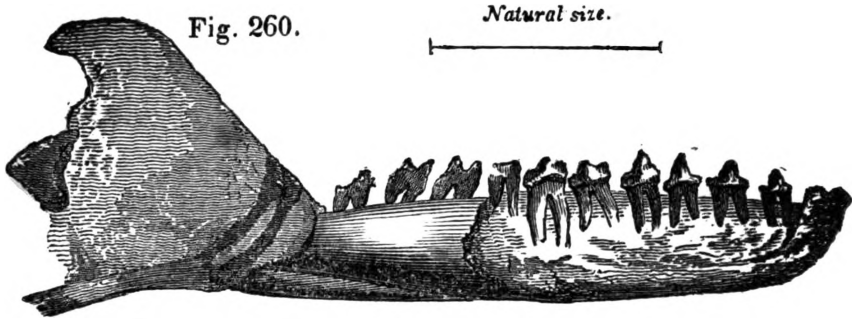
Natural size.

Phascolotherium Bucklandi, Owen. (Syn. *Didelphis Bucklandi*, Brod.)
Lower jaw, from Stonesfield.

1. The jaw magnified twice in length.

2. The second molar tooth magnified six times.

* See Buckland's *Bridgewater Treatise*.



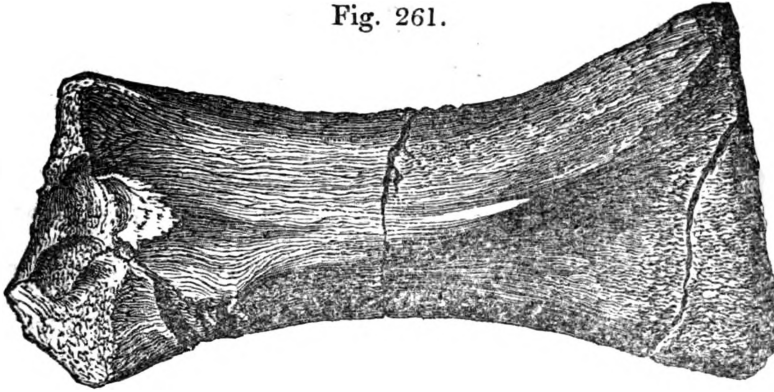
Thylacotherium Prevostii (Valenciennes). Lower jaw, from the slate of Stonesfield, near Oxford.

These fossils afford the only example yet known of terrestrial mammalia in rocks of a date anterior to the Eocene period.

This exception is the more deserving of notice, because even no cetacea have as yet been observed in any secondary strata, although certain bones, from the great oolite of Enstone, near Woodstock, in Oxfordshire, have been cited on the authority of Cuvier, as referable to this class. Dr. Buckland, who has stated this in his late *Bridgewater Treatise*,* has had the kindness to send me the supposed ulna of a whale, in order that Mr. Owen might examine into its claims to be considered as cetaceous. It is the opinion of that eminent comparative anatomist that it cannot have belonged to the cetacea, because the fore-arm in these marine mammalia is invariably much flatter, and devoid of all muscular depressions and ridges, one of which is so prominent in

* Vol. i. p. 115.

Fig. 261.

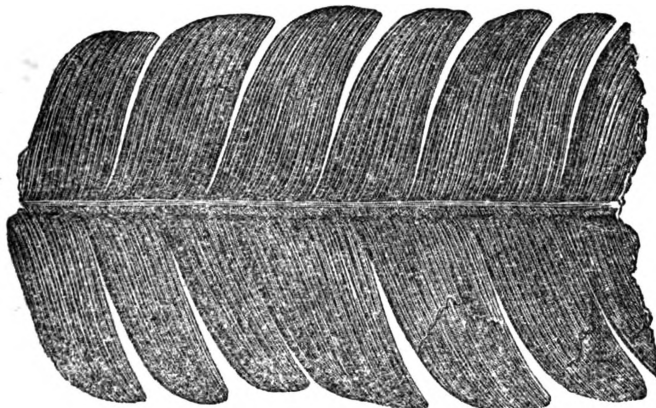


Bone of a reptile, formerly supposed to be the ulna of a Cetacean; from the Oolite of Enstone, near Woodstock.

the middle of this bone (see Fig. 261.). In saurians, on the contrary, such ridges exist for the attachment of muscles; and to some animal of that class the bone is probably referable.

Oolite of Yorkshire and Scotland.—North of the Humber, in Yorkshire, the Lower Oolite assumes a form very different from that which distinguishes it in the south. It may there be called a coal formation, as it contains much veg-

Fig. 262.



Pterophyllum comptum, (Syn. *Cycadites comptus*.) Upper sandstone and shale, Gristhorpe, near Scarborough.

etable matter, and coal, interstratified with sand and sandstones. The high state of preservation and number of the plants render it probable that land was not far distant. The same may be said of the oolitic coal of Brora, on the south-east coast of Sutherlandshire, in Scotland, where the Lower Oolite contains coal, one bed of which is $3\frac{1}{2}$ feet in thickness. The plants resemble those in the Yorkshire oolite, and a great number of the associated marine shells and other fossils are the same*; but the mineral characters of the sandstone, shale, and calcareous grit differ considerably.

* Murchison, Geol. Trans., vol. ii. Second Series.

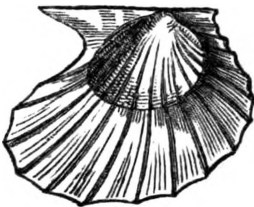
CHAPTER XXI.

OOLITE AND LIAS — *continued.*

Mineral character of Lias—Name of Gryphite limestone—Fossil fish—Ichthyodorulites—Reptiles of the Lias—Ichthyosaur and Plesiosaur—Newly-discovered marine Reptile of the Galapagos Islands—Sudden destruction and burial of fossil animals in Lias—Origin of the Oolite and Lias, and of alternating calcareous and argillaceous formations—Physical geography—Vales of clay—Hills and escarpments of limestone.

LIAS.—The English provincial name of Lias has been very gradually adopted for a formation of argillaceous limestone, marl, and clay, which forms the base of the Oolite, and is classed by many geologists as part of that group. They pass, indeed, into each other in some places, as near Bath, a sandy marl called the marlstone of the Lias being interposed, and partaking of the mineral characters of the upper lias and inferior oolite. These last-mentioned divisions have also some

Fig. 263.

*Avicula inæquivalvis*, Sow.

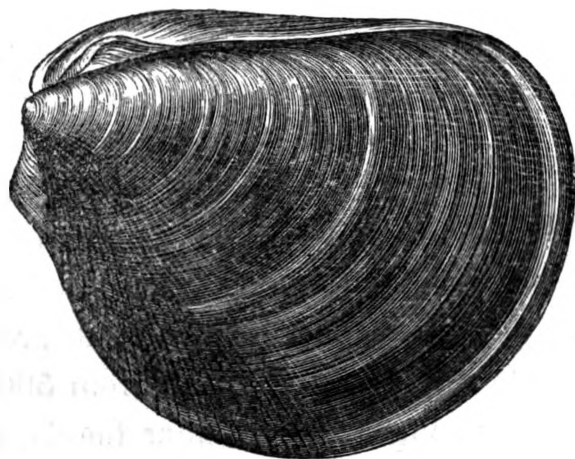
fossils in common, such as the *Avicula inæquivalvis* (Fig. 263.). Nevertheless the Lias may be traced throughout a great part of Europe as a separate and independent group, of considerable thickness, varying from 500 to 1000 feet, containing many peculiar fossils, and

having a very uniform lithological aspect. Although usually conformable to the oolite, it is sometimes, as in the Jura, unconformable. In the environs of Lons-le-Saulnier, for instance, the strata of lias are inclined at an angle of about 45° , while the incumbent oolitic marls are horizontal.

The peculiar aspect which is most characteristic of the lias in England, France, and Germany, is an alternation of thin beds of limestone with a light brown weathered surface, separated by dark-coloured narrow argillaceous partings, so that the quarries of this rock, at a distance, assume a striped and riband-like appearance.*

Although the prevailing colour of the limestone of this formation is blue, yet some beds of the lower lias are of a yellowish white colour, and have been called white lias. In some parts of France, near the Vosges mountains, and in Lux-

Fig. 264.



Plagiostoma giganteum. Lias.

* Conyb. and Phil. p. 261.

embourg, M. E. de Beaumont has shown that the lias containing *Gryphæa arcuata*, *Plagiostoma giganteum* (see Fig. 264.), and other characteristic fossils, becomes arenaceous; and around the Hartz, in Westphalia and Bavaria, the inferior parts of the lias are sandy, and sometimes afford a building stone.

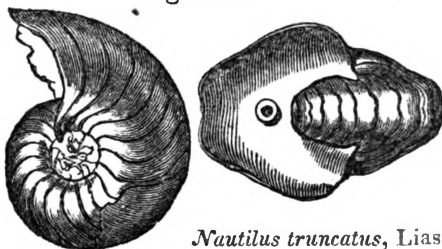
The name of Gryphite limestone has sometimes been applied to the lias, in consequence of the great number of shells which it contains of a species of oyster, or *Gryphæa* (Fig. 265., see also Fig. 30. p. 62.). Many cephalopoda, also, such as *Ammonite*, *Belemnite*, and *Nautilus* (Fig. 266.), prove the marine origin of the formation.

Fig. 265.



Gryphæa incurva, Sow.
(*G. arcuata*, Lam.)

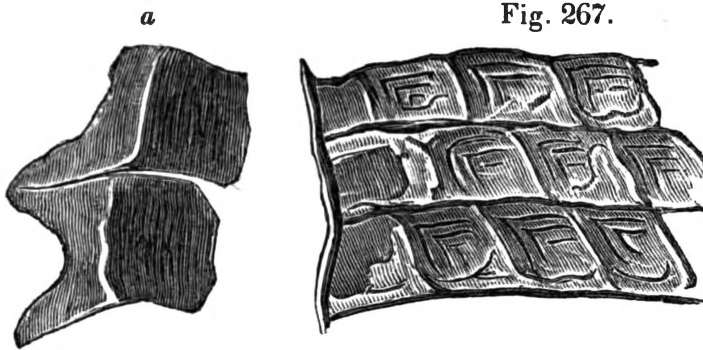
Fig. 266.



Nautilus truncatus, Lias.

The fossil fish resemble generically those of the oolite, belonging all, according to M. Agassiz, to extinct genera, and differing remarkably from the ichthyolites of the Cretaceous period. Among them is a species of *Lepidotus* (*L. gigas*, Agas.) (Fig. 267.), which is found in the lias of England, France, and Germany.* This genus was before

* Agassiz, Pois. Fos., vol. ii. tab. 28, 29.

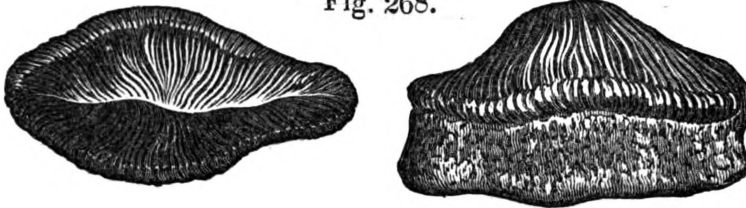


Scales of Lepidotus gigas, Agas.

a. two of the scales detached.

mentioned (Vol. I. p. 418.) as occurring in the Wealden, and is supposed to have frequented both rivers and coasts. The teeth of a species of *Acrodus*, also, are very abundant in the lias. (Fig. 268.).

Fig. 268.

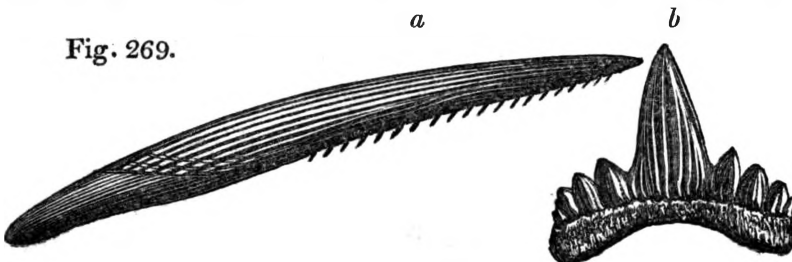


Acrodus nobilis, Agas. (tooth); commonly called fossil leach.

Lias, Lyme Regis, and Germany.

But the remains of fish which have excited more attention than any others, are those large bony spines called *ichthyodorulites* (*a*, Fig. 269.)

Fig. 269.



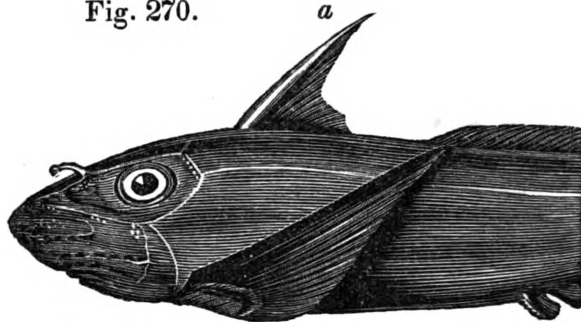
Hybodus reticulatus, Agas. Lias, Lyme Regis.

a. Part of fin, commonly called Ichthyodorulite.

b. Tooth

which were once supposed by some naturalists to be jaws, and by others weapons, resembling those of the living *Balistes* and *Silurus*; but which M. Agassiz has shown to be neither the one nor the other. The spines, in the genera last mentioned, articulate with the backbone, whereas there are no signs of any such articulation in the ichthyodorulites. These last appear to have been bony spines which formed the anterior part of the dorsal fin, like that of the living genera *Cestracion* and *Chimæra* (see *a*, Fig. 270.). In both of these

Fig. 270.

*Chimæra monstrosa.**

a. Spine forming anterior part of the dorsal fin.

genera, the posterior concave face is armed with small spines like that of the fossil *Hybodus* (Fig. 269.), one of the shark family found fossil at Lyme Regis. Such spines are simply imbedded in the flesh, and attached to strong muscles. "They serve," says Dr. Buckland, "as in the *Chimæra* (Fig. 270.), to raise and depress the fin, their action resembling that of a moveable mast,

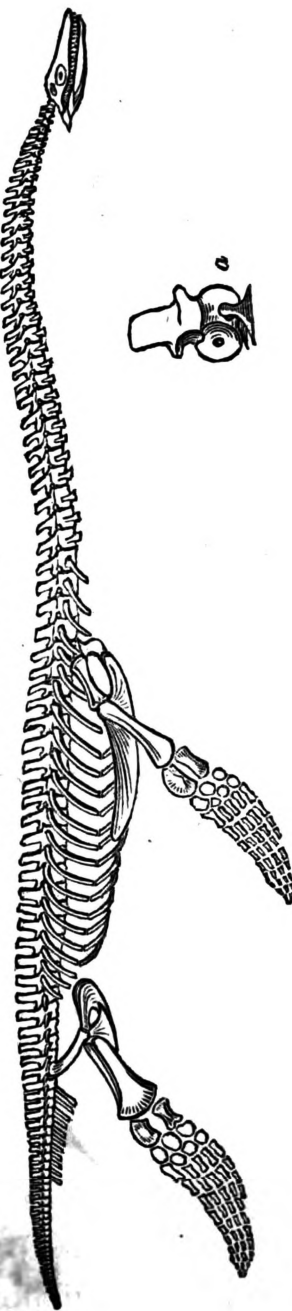
* Agassiz, Poissons Fossiles, vol. iii. tab. C. fig. 1.

Fig. 271.

*Ichthyosaurus communis*, restored by Conybeare and Cuvier.

a. costal vertebra.

Fig. 272.

*Plesiosaurus dolichodeirus*, restored by Rev. W. D. Conybeare.

a. cervical vertebra.

raising and lowering backwards the sail of a barge.” *

Reptiles of the Lias. — It is not, however, the fossil fish which form the most striking feature in the organic remains of the Lias ; but the reptiles, which are extraordinary for their number, size, and structure. Among the most singular of these are several species of *Ichthyosaurus* and *Plesiosaurus*. The genus *Ichthyosaurus*, or fish-lizard, is not confined to this formation, but has been found in strata as high as the chalk-marl and gault of England, and as low as the muschelkalk of Germany, a formation which immediately succeeds the lias in the descending order.† It is evident from their fish-like vertebræ, their paddles, resembling those of a porpoise or whale, the length of their tail, and other parts of their structure, that the habits of the Ichthyosaurs were aquatic. Their jaws and teeth show that they were carnivorous ; and the half-digested remains of fishes and reptiles, found within their skeletons, indicate the precise nature of their food.‡

Recently (1840) a specimen of the hinder fin of *Ichthyosaurus communis* has been discovered at Barrow-on-Soar, by Sir P. Egerton, which distinctly exhibits on its posterior margin the re-

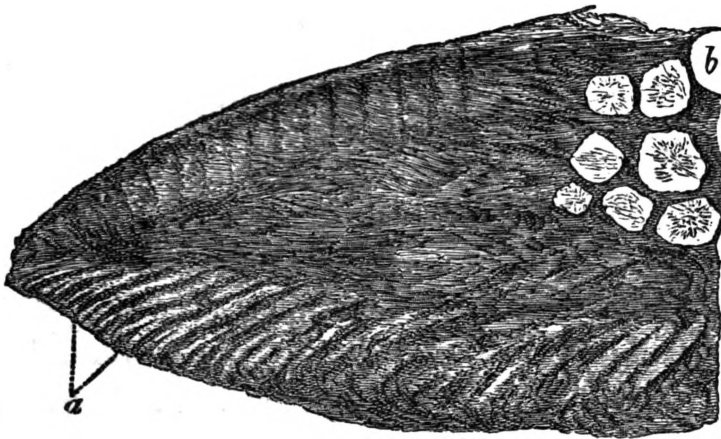
* Bridgewater Treatise, p. 290.

† Ibid. p. 168.

‡ Ibid. p. 187.

mains of cartilaginous rays that bifurcate as they approach the edge, like those in the fin of a fish. (See *a*, Fig. 273.) It had previously been supposed, says Mr. Owen, that the locomotive organs of the Ichthyosaurus were enveloped, while living, in a smooth integument, like that of the turtle and porpoise, which has no other support than is afforded by the bones and ligaments within; but it now appears that the fin was much larger, expanding far beyond its osseous framework, and deviating widely in its fish-like rays from the ordinary reptilian type. In the annexed figure the posterior bones, or digital ossicles of the paddle, are seen near *b*; and beyond these is

Fig. 273.



Posterior part of hind fin of *Ichthyosaurus communis*.

the dark carbonized integument of the terminal half of the fin, the outline of which is beautifully defined.*

* Geol. Soc. Proceedings, No. 66. p. 157.

Mr. Conybeare was enabled, in 1824, after examining many skeletons nearly perfect, to give an ideal restoration of the osteology of this genus, and of that of the *Plesiosaurus*.* (See Figs. 271, 272.) The latter animal had an extremely long neck and small head, with teeth like those of the crocodile, and paddles analogous to those of the *Ichthyosaurus*, but larger. It is supposed to have lived in shallow seas and estuaries, and to have breathed air like the Ichthyosaur, and our modern cetacea.† Some of the reptiles above mentioned were of formidable dimensions. One specimen of *Ichthyosaurus platyodon*, from the lias at Lyme, now in the British Museum, must have belonged to an animal more than twenty-four feet in length; and another of the *Plesiosaurus*, in the same collection, is eleven feet long. The form of the *Ichthyosaurus* may have fitted it to cut through the waves like the porpoise; but it is supposed that the *Plesiosaurus*, at least the long-necked species (Fig. 272.), was better suited to fish in shallow creeks and bays defended from heavy breakers.

For the last twenty years, anatomists have agreed that these extinct saurians must have inhabited the sea; and it was argued that, as there

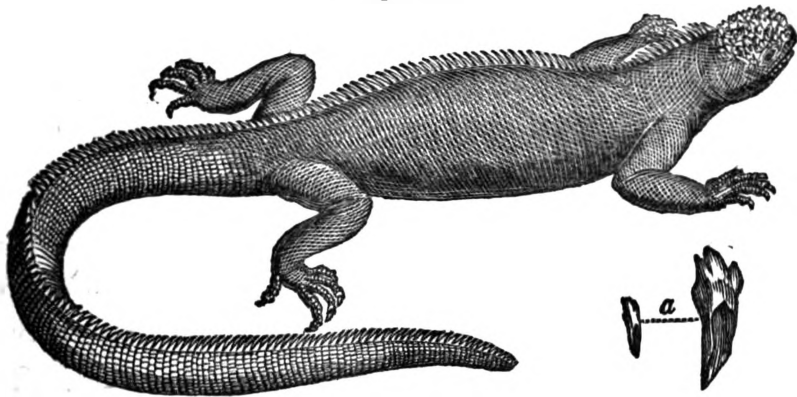
* Geol. Trans., Second Series, vol. i. pl. 49.

† Conybeare and De la Beche, Geol. Trans.; and Buckland, Bridgew. Treat., p. 203.

are now Chelonians, like the tortoise, living in fresh water, and others, as the turtle, frequenting the ocean, so there may have been formerly some saurians proper to salt, others to fresh water. The common crocodile of the Ganges is well known to frequent equally that river and the brackish and salt water near its mouth; and crocodiles are said in like manner to be abundant both in the rivers of the Isla de Pinos (or Isle of Pines), south of Cuba, and in the open sea round the coast. More recently a saurian has been discovered of aquatic habits and exclusively marine. This creature was found in the Galapagos islands, during the visit of H. M. S. Beagle to that archipelago, in 1835, and its habits were then observed by Mr. Darwin. The islands alluded to are situated under the equator, nearly 600 miles to the westward of the coast of South America. They are volcanic, some of them being 3000 or 4000 feet high; and one of them, Albemarle Island, 75 miles long. The climate is mild, very little rain falls; and, in the whole archipelago, there is only one rill of fresh water that reaches the coast. The soil is for the most part dry and harsh, and the vegetation scanty. The birds, reptiles, plants, and insects are, with very few exceptions, of species found nowhere else in the world, although all partake, in their general form, of an American character. Of the mammalia, says Mr.

Darwin, one species alone appears to be indigenous, namely, a large and peculiar kind of mouse ; but the number of lizards, tortoises, and snakes is so great, that it may be called a land of reptiles. The variety, indeed, of species is small ; but the individuals of each are in wonderful abundance. There is a turtle, a large tortoise (*Testudo Indicus*), four lizards, and about the same number of snakes, but no frogs or toads. Two of the lizards belong to the family *Iguanidæ* of Bell, and to a peculiar genus (*Amblyrhynchus*) established by that naturalist, and so named from their obtusely truncated head and short snout.* Of these lizards one is terrestrial in its habits, and burrows in the ground, swarming everywhere on the land, having a round tail, and a mouth somewhat resembling in form that of the tortoise. The other is aquatic, and has its tail flattened laterally for

Fig. 274.



Amblyrhynchus cristatus, Bell. Length varying from 3 to 4 ft. The only existing marine lizard now known.

a. Tooth, natural size and magnified.

* *Ἀμβλυνος*, amblys, blunt ; and *ῥυγχος*, rhynchus, snout.

swimming (see Fig. 274.). "This marine saurian," says Mr. Darwin, "is extremely common on all the islands throughout the archipelago. It lives exclusively on the rocky sea-beaches, and I never saw one even ten yards inshore. The usual length is about a yard, but there are some even four feet long. It is of a dirty black colour, sluggish in its movements on the land; but, when in the water, it swims with perfect ease and quickness by a serpentine movement of its body and flattened tail, the legs during this time being motionless, and closely collapsed on its sides. Their limbs and strong claws are admirably adapted for crawling over the rugged and fissured masses of lava which everywhere form the coast. In such situations a group of six or seven of these hideous reptiles may oftentimes be seen on the black rocks, a few feet above the surf, basking in the sun with outstretched legs. Their stomachs, on being opened, were found to be largely distended with minced sea-weed, of a kind which grows at the bottom of the sea at some little distance from the coast. To obtain this, the lizards go out to sea in shoals. One of these animals was sunk in salt water, from the ship, with a heavy weight attached to it, and on being drawn up again after an hour it was quite active and unharmed. It is not yet known by the inhabitants where this animal lays its eggs; a singular fact, considering

its abundance, and that the natives are well acquainted with the eggs of the terrestrial *Amblyrhynchus*, which is also herbivorous.” *

In those deposits now forming by the sediment washed away from the wasting shores of the Galapagos islands the remains of saurians, both of the land and sea, as well as of chelonians and fish, may be mingled with marine shells without any bones of land quadrupeds or batrachian reptiles ; yet even here we should expect the remains of marine mammalia to be imbedded in the new strata, for there are seals, besides several kinds of cetacea, on the Galapagian shores ; and, in this respect, the parallel between the modern fauna, above described, and the ancient one of the lias, would not hold good.

Sudden destruction of saurians, &c.—It has been remarked, and truly, that many of the fish and saurians, found fossil in the lias, must have met with sudden death and immediate burial ; and that the destructive operation, whatever may have been its nature, was often repeated.

“ Sometimes,” says Dr. Buckland, “ scarcely a single bone or scale has been removed from the place it occupied during life ; which could not have happened had the uncovered bodies of these saurians been left, even for a few hours, exposed

* Darwin’s Journal, chap. xix. (For full title, see note, p. 168.)

to putrefaction, and to the attacks of fishes and other smaller animals at the bottom of the sea.”* Not only are the skeletons of the Ichthyosaurs entire, but sometimes the contents of their stomachs still remain between their ribs, so that we can discover the particular species of fish on which they lived, and the form of their excrements. Not unfrequently there are layers of these coprolites at different depths in the lias, at a distance from any entire skeletons of the marine lizards from which they were derived ; “ as if,” says Mr. De la Beche, “ the muddy bottom of the sea received small sudden accessions of matter from time to time, covering up the coprolites and other exuviae which had accumulated during the intervals.”† It is further stated that, at Lyme Regis, those surfaces only of the coprolites which lay uppermost at the bottom of the sea have suffered partial decay, from the action of water before they were covered and protected by the muddy sediment that has afterwards permanently enveloped them.‡

Numerous specimens of the pen-and-ink fish (*Sepia loligo*, Lin. ; *Loligo vulgaris*, Lam.) have also been met with in the lias at Lyme, with the ink-bags still distended, containing the ink in a dried state, chiefly composed of carbon, and but

* Bridgew. Treat., p. 125.

† Geological Researches, p. 334.

‡ Buckland, Bridgew. Treat., p. 307.

slightly impregnated with carbonate of lime. These cephalopoda, therefore, must, like the saurians, have been soon buried in sediment; for, if long exposed after death, the membrane containing the ink would have decayed.*

As we know that river fish are sometimes stifled, even in their own element, by muddy water during floods, it cannot be doubted that the periodical discharge of large bodies of turbid fresh water into the sea may be still more fatal to marine tribes. In the Principles of Geology, I have shown that large quantities of mud and drowned animals have been swept down into the sea by rivers during earthquakes, as in Java, in 1699; and that undescribable multitudes of dead fishes have been seen floating on the sea after a discharge of noxious vapours during similar convulsions.† But, in the intervals between such catastrophes, strata may have accumulated slowly in the sea of the lias, some being formed chiefly of one description of shell, such as ammonites, others of gryphites.

Fossil plants.—Among the vegetable remains of the Lias, several species of *Zamia* have been found at Lyme Regis, and the remains of coniferous plants at Whitby. Fragments of wood are

* Buckland, Bridgew. Treat., p. 367.

† See Principles, *Index*, Lancerote, Graham Island, Calabria.

common, and often converted into limestone. That some of this wood, though now petrified,

Fig. 275.



was soft when it first lay at the bottom of the sea, is shown by a specimen now in the museum of the Geological Society (see Fig. 275.), which has the form of an *ammonite* indented on its surface.

Origin of the Oolite and Lias.—If we now endeavour to restore, in imagination, the ancient condition of the European area at the period of the Oolite and Lias, we must conceive a sea in which the growth of coral reefs and shelly limestones, after proceeding without interruption for ages, was liable to be stopped suddenly by the deposition of clayey sediment. Then, again, the argillaceous matter, devoid of corals, was deposited for ages, and attained a thickness of hundreds of feet, until another period arrived when the same space was again occupied by calcareous sand, or solid rocks of shell and coral, to be again succeeded by the recurrence of another period of argillaceous deposition. Mr. Conybeare has remarked of the entire group of Oolite and Lias, that it consists of repeated alternations of clay, sandstone, and limestone, following each other in the same order. Thus the clays of the lias are followed by the sands of the inferior oolite, and

these again by shelly and coralline limestone (Bath oolite, &c.) ; so, in the middle oolite, the Oxford clay is followed by calcareous grit and " coral rag ;" lastly, in the upper oolite the Kimmeridge clay is followed by the Portland sand and limestone.* The clay beds, however, as Mr. De la Beche remarks, can be followed over larger areas than the sands or sandstones.† It should also be remembered that while the oolitic system becomes arenaceous, and resembles a coal-field in Yorkshire, it assumes, in the Alps, an almost purely calcareous form, the sands and clays being omitted ; and even in the intervening tracts, it is more complicated and variable than appears in ordinary descriptions. Nevertheless, some of the clays and intervening limestones do, in reality, retain a pretty uniform character, for distances of from 400 to 600 miles from east to west and north to south.

According to M. Thirria, the entire oolitic group in the department of the Haute Saône, in France, may be equal in thickness to that of England ; but the importance of the argillaceous divisions is in the inverse ratio to that which they exhibit in England, where they are about equal to twice the thickness of the limestones, whereas, in the part of France alluded to, they

* Con. and Phil., p. 166.

† Geol. Researches, p. 337.

reach only about a third of that thickness.* In the Jura the clays are still thinner; and in the Alps they thin out and almost vanish.

In order to account for such a succession of events, we may imagine, first, the bed of the ocean to be the receptacle for ages of fine argillaceous sediment, brought by oceanic currents, which may have communicated with rivers, or with part of the sea near a wasting coast. This mud ceases, at length, to be conveyed to the same region, either because the land which had previously suffered denudation is depressed and submerged, or because the current is deflected in another direction by the altered shape of the bed of the ocean and neighbouring dry land. By such changes the water becomes once more clear and fit for the growth of stony zoophytes. Calcareous sand is then formed from comminuted shell and coral, or, in some cases, arenaceous matter replaces the clay; because it commonly happens that the finer sediment, being first drifted farthest from coasts, is subsequently overspread by coarse sand, after the sea has grown shallower, or when the land, increasing in extent, has approached nearer to the spots first occupied by fine mud.

In order to account for another great formation, like the Oxford clay, again covering one of

* Burat's D'Aubuisson, tom. ii. p. 456.

coral limestone, we must suppose a sinking down like that which is now taking place in some existing regions of coral between Australia and South America.* The occurrence of subsidences, on so vast a scale, may again have caused the bed of the ocean and the adjoining land, throughout great parts of the European area, to assume a shape favourable to the deposition of another set of clayey strata; and this change may have been succeeded by a series of events analogous to that already explained, and these again by a third series in similar order. Both the ascending and descending movements may have been extremely slow, like those now going on in the Pacific; and the growth of every stratum of coral, a few feet in thickness, may have required centuries for its completion, during which certain species of organic beings may have disappeared from the earth, and others have been introduced in their place; so that, in each set of strata, from the Upper Oolite to the Lias, some peculiar and characteristic fossils were imbedded.

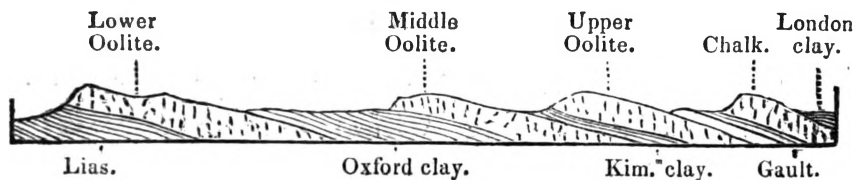
Physical geography.—The alternation, on so large a scale, of distinct formations of clay and limestone, has given rise to some marked features in the physical outline of parts of England and France. Wide valleys can usually be traced

* See Darwin's Journal, chap. xxii.

throughout the long bands of country where the argillaceous strata crop-out ; and between these valleys the limestones are observed, composing ranges of hills, or more elevated grounds. These ranges terminate abruptly on the side on which the several clays crop-out from beneath the calcareous strata.

The annexed diagram will give the reader an idea of the configuration of the surface now alluded to, such as may be seen in passing from London to Cheltenham, or in other parallel lines, from east to west, in the southern part of England. It has been necessary, however, in this

Fig. 276.



drawing, greatly to exaggerate the inclination of the beds, and the height of the several formations, as compared to their horizontal extent. It will be remarked, that the lines of cliff, or escarpment, face towards the west in the great calcareous eminences formed by the Chalk and the Upper, Middle, and Lower Oolites ; and at the base of each we have respectively the Gault, Kimmeridge clay, Oxford clay, and Lias. This last forms, generally, a broad vale at the foot of the

escarpment of Inferior Oolite ; but a considerable portion of that escarpment is sometimes occupied by lias. The external outline of the country which the geologist observes in travelling eastward from Paris to Metz is precisely analogous, and is caused by a similar succession of rocks intervening between the tertiary strata and the Lias ; with this difference, however, that the escarpments of Chalk, Upper, Middle, and Lower Oolites, face towards the east instead of the west.

The Chalk crops-out from beneath the tertiary sands and clays of the Paris basin, near Epernay, and the Gault from beneath the Chalk and Upper Green-sand at Clermont en Argonne ; and passing from this place by Verdun and Etain to Metz, we find two limestone ranges, with intervening vales of clay, precisely resembling those of southern and central England, until we reach the great plain of Lias at the base of the Inferior Oolite at Metz.

It is evident, therefore, that the denuding causes have acted similarly over an area several hundred miles in diameter, sweeping away the softer clays more extensively than the limestones, and undermining these last so as to cause them to form steep cliffs wherever the harder calcareous rock was based upon a more yielding and destructible clay. This denudation probably occurred while the land was slowly rising out of the sea.*

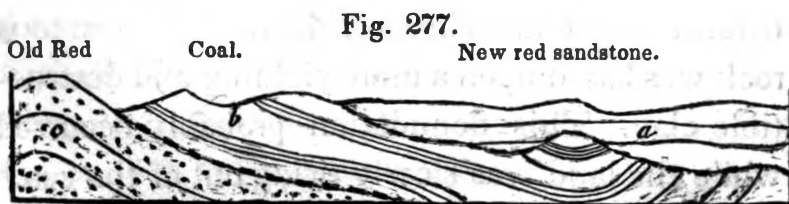
* See Chapters 6, and 19.

CHAPTER XXII.

NEW RED SANDSTONE GROUP.

Distinction between New and Old Red sandstone—Between Upper and Lower New Red—Bone-bed of Axmouth and Aust—Red sandstone of Warwickshire and Cheshire—Footsteps of *Chirotherium* in England and Germany—Osteology of the *Labyrinthodon*—Identification of this Batrachian with the *Chirotherium*—Gypsum and rock-salt in Upper New Red—Trias of the Germans—Its fossils—Muschelkalk—Lower New Red and Magnesian limestone—Zechstein in Germany of the same age—Points of analogy between the organic remains of the Magnesian limestone and Carboniferous strata—Heterocercal fish—Saurians of the Lower New Red—Origin of red sandstone and red marl.

BETWEEN the Lias and the Coal, or Carboniferous group, there is interposed, in the midland and western counties of England, a great series of red marls and sandstones, to which the name of the New Red Sandstone formation was given, to distinguish it from other marls and sandstones called the "Old Red" (*c*, Fig. 277.), often identical in mineral character, which lie immediately beneath the coal, *b*.



In some parts of the south-west of England, the entire "New Red" group consists exclusively of red loam, clay, and sandstone, devoid of fossils, strongly contrasted in colour, and the general absence of calcareous matter, with the Oolitic rocks and Lias before described. But when we extend our observations over England and other countries, we no longer find this simplicity of structure ; but perceive that the strata between the Lias and the Coal are divisible into two very distinct systems, which will be understood from the accompanying Table, and the description which follows.

NEW RED SANDSTONE GROUP.

*Poikilitic group of Conybeare and Buckland.**

		Synonyms.	
		German.	French.
1. Upper new red.	a. Saliferous marls and sandstone -	Keuper	Marnes irisées.
	b. (wanting in England) -	Muschelkalk	Muschelkalk, ou calcaire coquillier.
	c. Sandstone and quartzose conglomerate -	Bunter sandstein	Grès bigarré.
2. Lower new red.	d. Magnesian limestone (dolomitic conglomerate) -	Zechstein, and Kupfer schiefer	Zechstein, ou schiste cuivreux — et Calcaire Magnésien
	e. Lower New Red sandstone.	Roth-liegen-des	Grès des Vosges, couches inférieures ?

* From *ποικίλος*, *Poikilos variegated* (see Buckland, Bridg. Treat., vol.ii. p.38.), because some of the most characteristic strata of this group were called *variegated* by Werner, from their exhibiting spots and streaks of light blue, green, and buff colour, in a red base.

UPPER NEW RED SANDSTONE.

(*Trias of the Germans.*)

The Lias is succeeded in England by conformable strata of red and green marl, or clay. There intervenes, however, both in the neighbourhood of Axmouth, in Devonshire, and in the cliffs of Westbury and Aust, in Gloucestershire, on the banks of the Severn, a dark-coloured stratum, well known by the name of the "bone-bed." It abounds in the remains of saurians and fish, and was formerly classed as the lowest bed of the Lias; but Sir P. Egerton has lately shown that it should be referred to the Upper New Red Sandstone, for it contains an assemblage of fossil fish which are either peculiar to this stratum, or belong to species well known in the Continental Muschelkalk. These fish belong to the genera *Acrodus*, *Hybodus*, *Gyrolepis*, and *Saurichthys*.

Among those common to the English bone-bed and the Muschelkalk of Germany are *Hybodus plicatilis* (Fig. 278.), *Saurichthys apicalis* (Fig.

Fig. 278.



Hybodus plicatilis. Teeth. Bone-bed, Aust and Axmouth.

Fig. 279.



Saurichthys apicalis.
Tooth ; nat. size, and magnified.
Axmouth.

Fig. 280.



Gyrolepis tenuistriatus.
Scale, nat. size, and magnified.
Axmouth.

279.), *Gyrolepis tenuistriatus* (Fig. 280.), and *G. Albertii*. Remains of saurians have also been found in the bone-bed, and plates of an *Encrinus*.

The strata of red and green marl, which follow the bone-bed in the descending order at Axmouth and Aust, are destitute of organic remains ; as is the case, for the most part, in the corresponding beds in almost every part of England. But fossils have lately been found at a few localities in sandstones of this formation, and among them the bivalve shell called *Posidonia minuta*, Goldf. (Fig. 289. p. 93.), as in Worcestershire and Warwickshire. Impressions, also, of the footsteps of several animals have been detected in the country last named, and in Cheshire ; among which some of the most remarkable occur a few miles from Liverpool, in the sandstone of Storeton Hill, on the west side of the Mersey. They bear a close resemblance to the tracks previously observed in

a member of the Upper New Red Sandstone, at the village of Hesseberg, near Hildburghausen, in Saxony, which had been for many years referred to a large unknown quadruped, provision-

Fig. 281.



Single footprint of *Chirotherium*. Bunter Sandstein, Saxony; one eighth of nat. size.

ally named *Chirotherium* by Professor Kaup, because the marks both of the fore and hind feet resembled impressions made by a human hand.

(See Fig. 281.) The footmarks at Hesseberg are partly concave and partly in relief;

the former, or the depressions, are upon the upper surface of the sandstone slabs, but those in relief are only upon the lower surfaces, being in fact natural casts, formed in the subjacent foot-prints as in moulds. The larger impressions, which seem to be those of the hind foot, are generally eight inches in length, and five in width, and one was twelve inches long. Near each large footprint, and at a regular distance (about an inch and a half) before it, a smaller

Fig. 282.



Line of footsteps on slab of sandstone. Hildburghausen, in Saxony.

print of a fore foot, four inches long and three inches wide, occurs. The footsteps follow each

other in pairs, each pair in the same line, at intervals of 14 inches from pair to pair. The large as well as the small steps show the great toes alternately on the right and left side ; each step makes the print of five toes, the first or great toe being bent inwards like a thumb. Though the fore and hind foot differ so much in size, they are nearly similar in form.

The description here given of fossil footsteps observed in Germany, answers with singular accuracy to those afterwards found in a formation of the same age in England. They occur at Storeton on the Mersey, on five thin beds of clay, superimposed one upon the other in the same quarry, and separated by beds of sandstone. On the lower surface of the sandstone strata the solid casts of each impression are salient, in high relief, and afford models of the feet, toes, and claws of the animals which trod on the clay.

As neither in Germany nor in England any bones or teeth are met with in the same identical strata as the footsteps, anatomists indulged, for several years, in various conjectures respecting the mysterious animals from which they might have been derived. Professor Kaup suggested that the unknown quadruped might have been allied to the *Marsupialia* ; for in the kangaroo the first toe of the fore foot is in a similar manner set obliquely to the others, like

a thumb, and the disproportion between the fore and hind feet is also very great. But M. Link conceived that some of the four species of animals of which the tracks had been found in Saxony might have been gigantic *Batrachians* ; and Dr. Buckland designated some of the footsteps as those of a small web-footed animal, probably crocodilean.

In the course of these discussions several naturalists of Liverpool, in their report on the Storeton quarries, declared their opinion that each of the thin seams of clay in which the sandstone casts were moulded had formed successively a surface above water, over which the *Chirotherium* and other animals walked, leaving impressions of their footsteps, and that each layer had been afterwards submerged by a sinking down of the surface, so that a new beach was formed at low water above the former, on which other tracks were then made. In the same manner, the repeated occurrence of ripple-marks at various heights and depths in the red sandstone of Cheshire had been explained. Several geologists had also remarked that impressions of such depth and clearness could only have been made by animals walking on dry land, as their weight could not have been sufficient to cause them to sink so deeply in yielding clay under water.

When the inquiry had been brought to this

point the reptilian remains hitherto discovered in the Upper New Red, both of Germany and England, were carefully examined by Mr. Owen. He found, after a microscopic investigation of the teeth from the German sandstone called Keuper, and from the sandstone of Warwick and Leamington, that neither of them could be referred to true saurians, although they had been named *Mastodonsaurus* and *Phytosaurus* by Jäger (Fig. 283.). It appeared that they were of the *Batrachian* order, and attested the former existence of frogs of gigantic dimensions in comparison with any now living.

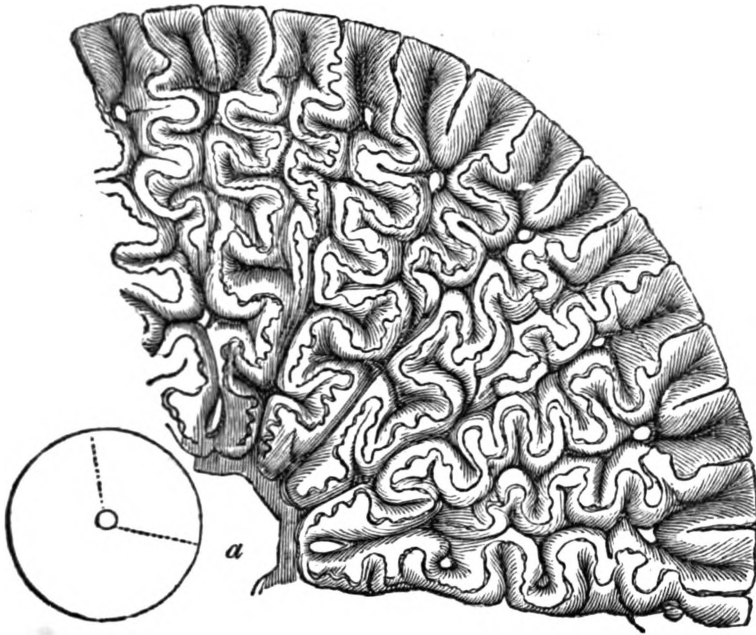
Fig. 283.



Tooth of *Labyrinthodon*; nat. size. Warwick sandstone.

Both the Continental and English fossil teeth exhibited a most complicated texture, differing from that previously observed in any reptile, whether recent or extinct, but most nearly analogous to the *Ichthyosaurus*. A section of one of these teeth exhibits a series of irregular folds, resembling the labyrinthic windings of the surface of the brain; and from this character Mr. Owen has proposed the name of the *Labyrinthodon* for the new genus. By his permission, the annexed representation of one is given from his "Odontography," plate 64. A. (Fig. 284.). The entire length of the tooth is supposed to have been about three inches and a half, and the breadth at the base one inch and a half.

Fig. 234.



Transverse section of tooth of *Labyrinthodon Jaegeri*, Owen (*Mastodonsaurus Jaegeri*, Meyer.) Nat. size, and a segment magnified.

a. Pulp cavity, from which the processes of pulp and dentine radiate.

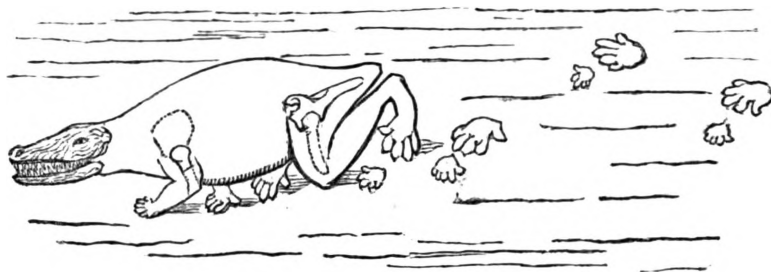
When Mr. Owen had satisfied himself, from an inspection of the cranium, jaws, and teeth, that a gigantic *Batrachian* had existed at the period of the Upper New Red Sandstone, he soon found, from the examination of various bones derived from the same formation, that he could define three species of *Labyrinthodon*, and that in this genus the hind extremities were much larger than the anterior extremities. This circumstance, coupled with the fact of the *Labyrinthodon* having existed at the period when the *Chyrotherian* foot-steps were made, was the first step towards the identification of those tracks with the newly dis-

covered *Batrachian*. It was at the same time observed that the foot-marks of *Chirotherium* were more like those of toads than of any other living animal ; and, lastly, that the size of the three species of *Labyrinthodon* corresponded with the size of three different kinds of foot-prints which had already been supposed to belong to three distinct *Chirotheria*. It was, moreover, inferred with confidence that the *Labyrinthodon* was an air-breathing reptile, from the structure of the nasal cavity, in which the posterior outlets were at the back part of the mouth, instead of being directly under the anterior or external nostrils. It must have respired air after the manner of saurians, and may therefore have imprinted on the shore those footsteps, which, as we have seen, could not have originated from an animal walking under water.

It is true that the structure of the foot is still wanting, and that a more connected and complete skeleton is required for demonstration ; but the circumstantial evidence above stated is strong enough to produce the conviction that the *Chirotherium* and *Labyrinthodon* are one and the same.

In order to show the manner in which one of these formidable *Batrachians* may have impressed the mark of its feet upon the shore, Mr. Owen has attempted a restoration, of which a greatly reduced copy is annexed.

Fig. 285.

*Labyrinthodon pachygnathus*, Owen.

The only bones of this species at present known are those of the head, the pelvis, and part of the scapula, which are shown by stronger lines in the above figure. There is reason for believing that the head was not smooth externally, but protected by bony scutella.

The term "Saliferous Marl and Sandstone" has been applied to the Upper New Red System, because it is in this group that rock-salt and salt springs occur in Cheshire and other parts of England, where the alternating beds of red and green marl, gypsum, and rock-salt sometimes exceed 600 feet in thickness. The gypsum is generally fibrous, and intercalated very irregularly between the laminated argillaceous beds. The rock-salt is sometimes clear and white, but is usually reddened by the argillaceous sediment with which it is associated. At Northwich, in Cheshire, are two beds of solid rock-salt, which are, together, not less than 60 feet in thickness. The origin of these vast deposits of muriate of

soda is still one of the most obscure problems in theoretical geology.

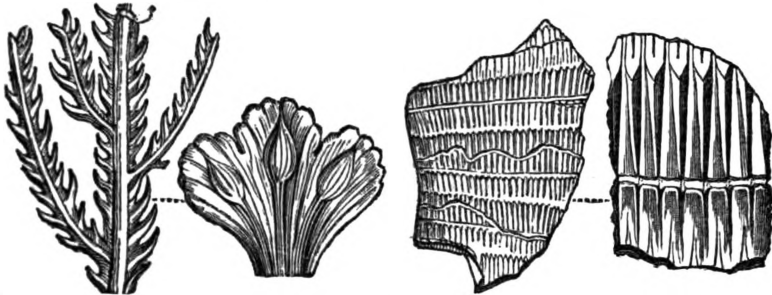
In Germany, the Upper New Red Sandstone is far more fully developed than in England, and has been called the Trias, or triple group; comprising the Keuper, Muschelkalk, and Bunter Sandstein (see Table, p. 81.). If we examine this group in Bavaria and Wurtemberg, we find that first in order beneath the Lias come mottled marls and sandstones, red, green, purple, and white, containing gypsum and salt. These constitute the Keuper; then follows the Muschelkalk, or shelly-limestone, rich in organic remains; and then another set of marls and sandstones, much resembling the first or Keuper division, and called "Bunter," from their variegated and spotted character. That these three formations belong to one great period, appears from the fact that Count Munster has obtained many of the same plants from the Keuper and Bunter Sandstein; and M. Agassiz the same species of fish from both of them, and from the interposed Muschelkalk. It is also worthy of remark, that the strata of the Muschelkalk alternate with those of the Keuper and Bunter Sandstein at their junction.

The fossil Flora, above alluded to, consists of *Cycadeæ* and several genera of ferns; also extinct *Coniferæ* of the genus *Voltzia* (Ad. Brongniart)

peculiar to this period, in which even the fructification has been preserved (Fig. 286.), and a gigantic species of *Equisetum* (Fig. 287.), which is not uncommon in the Keuper sandstone.

Fig. 286.

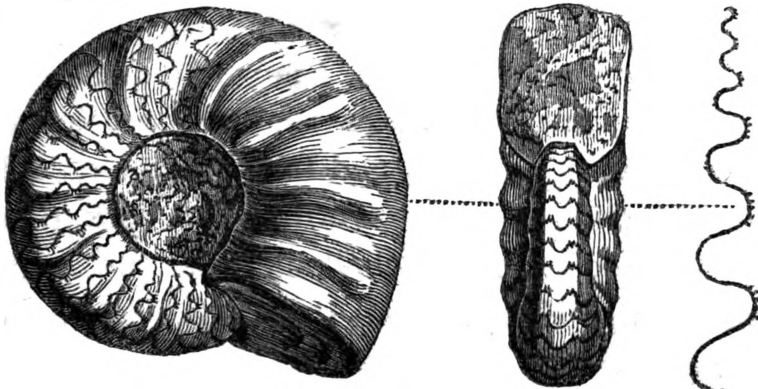
Fig. 287.



Voltzia brevifolia, and portion magnified to show fructification; Sulzbad. Keuper and Bunter Sandstein.

Equisetum columnare; fragment of stem and small portion of same magnified. Keuper.

Among the shells, some of the Cephalopoda are peculiar; as, for example, that form of *Ammonite* which is called *Ceratite* by De Haan, in which the descending lobes (see *a*, *b*, *c*, Fig. 288.) ter-

Fig. 288. *a**b**c*

Ammonites nodosus. Muschelkalk.

a. Side view.*b*. Front view.

c. Partially denticulated outline of the septa dividing the chambers.

minate in a few small denticulations pointing inwards. Among the bivalve shells, the *Posidonia minuta*, Goldf. (*Posidonomya minuta*, Bronn), Fig. 289., is abundant, ranging from the Keuper to the Bunter Sandstein; and *Avicula socialis* (Fig. 290.), having a similar range, but

Fig. 289.



Posidonia minuta,
Goldf. (*Posido-
nomya minuta*,
Bronn.)

a

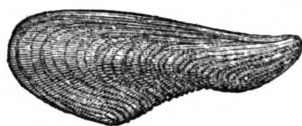
a. *Avicula socialis*.

Fig. 290.

b



b. Side view of same.

Characteristic of the Muschelkalk.

most characteristic of the Muschelkalk in Germany, France, and Poland.

There are also some encrinites in the Muschelkalk, and some teeth of cartilaginous fish; a few decapod crustacea; and large extinct reptiles of peculiar forms, such as the *Labyrinthodon* before mentioned, to which the fossil footsteps of the Bunter Sandstein of Hildburghausen seem to be referable. Upon the whole, Professor Bronn has enumerated, in his "Lethæa Geognostica," no less than forty-seven genera of fossil remains from the three divisions of the "Upper New Red" system in Germany; and these fossils are the more important, as being all distinct in species, and many of them in genera, from those of the incumbent Lias, or more ancient Magnesian limestone.

It would scarcely be possible to draw a distinct line of demarcation between the Keuper and Bunter Sandstein, even in Germany, where they are not barren of fossils, if the Muschelkalk did not intervene between them. In England, therefore, where this calcareous formation is wanting, and where there are scarcely any organic remains in the Upper New Red marl and sandstone, we cannot feel assured that the divisions *a.* and *c.* of our Table, p. 81., do really coincide with the German Keuper and Bunter Sandstein. But it has been found convenient in the counties of Salop, Stafford, and Worcester, to divide the saliferous marls from the inferior quartzose conglomerate in the manner above indicated.

LOWER NEW RED SANDSTONE AND MAGNESIAN
LIMESTONE GROUP.

We now come to the Magnesian Limestone or Lower New Red Sandstone group, the position of which can be best determined in Germany, because it is there interposed between the Coal and Bunter Sandstein, or oldest part of the "Upper New Red," above described. In the south-west of England the New Red sandstone formation is unconformable to the Coal (see Fig. 277.); but in the north-east of England Professor Sedgwick has shown that the same series is conformable to the carboniferous strata, and passes

into them. In other words, the movements which deranged "the Coal" in the south-west, previously to the origin of the New Red sandstone, did not extend towards Durham and the more northern counties.

Near Bristol in Somersetshire, and in other counties bordering the Severn, the unconformable beds of the Lower New Red, resting immediately upon the Coal, consist of a conglomerate called "dolomitic," because the pebbles of older rocks are cemented together by a red or yellow base of dolomite or magnesian limestone. This conglomerate or breccia, for the imbedded fragments are sometimes angular, occurs in patches over the whole of the downs near Bristol, filling up the hollows and irregularities in the mountain limestone, and being principally composed at every spot of the debris of those rocks on which it immediately rests. At one point we find pieces of coal shale, in another of mountain limestone of large size, and exhibiting its peculiar shells and zoophytes. Fractured bones also of saurians and some teeth are dispersed throughout the breccia; and they all belong, as will be seen in the sequel, to genera of a peculiar type. (see p. 100.)

In the north-east of England the dolomitic conglomerate is represented by a yellow limestone, generally called the Magnesian Limestone, which passes upwards into marl slate, and down-

wards into red marl and gypsum. In the intermediate counties of Worcester, Stafford, and Salop, are conglomerates referred to the same age, but which are calcareous, with scarcely any magnesia. Between these conglomerates and the Coal is a great formation, called the Lower New Red Sandstone (see Table, p.81.), composed of sandstones, red shales, and marls, occasionally spotted green.*

The country of Mansfeld, in Thuringia, may be called the classic ground of the Lower New Red, or Magnesian Limestone formation, on the Continent. It has there been long celebrated, because one of its members, a slaty marlstone, is richly impregnated with copper pyrites, for which it is extensively worked. The formation in that country is composed of an upper calcareous division, called the Zechstein, and a lower red quartzose formation of sandstone and conglomerate, called the Rothliegendes. The upper of these systems is very complex, consisting of marl, limestone, copper-slate, magnesian limestone, gypsum, and rock-salt, in which numerous fossils occur, bearing a striking generic resemblance to those of our English Magnesian Limestone. The Lower system, or Rothliegendes, is interposed between the Zechstein and the Coal ; and is supposed to

* Murchison, Silurian System, p. 54.

correspond with the Lower New Red Sandstone above mentioned, as occupying a similar place in England between our Magnesian Limestone and Coal. Its local name of Rothliegendes, *red-lyer*, or "Roth-todt-liegendes," *read-dead-lyer*, was given by the workmen in the German mines from its red color, and because the copper has *died out* when they reach this rock, which is not metalliferous. It is, in fact, a great deposit of red sandstone and conglomerate, with associated porphyry, basaltic trap, and amygdaloid.

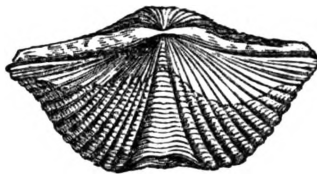
When we consider the fossils of the Magnesian Limestone in England, or corresponding Zechstein in Germany, we find that they approach much nearer in their character to the organic remains of the older Carboniferous group than to those of the Upper New Red. Thus, for example, the two genera of shells, *Producta* and *Spirifer*,

Fig. 291.



Producta calva, Sow.
(*Leptæna*, Dalman.)
Magnesian Limestone.

Fig. 292.

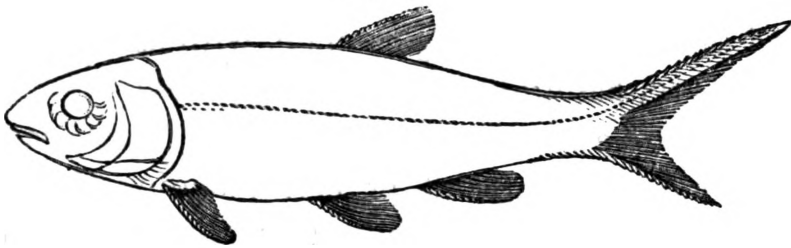


Spirifer undulatus, Sow.
Magnesian Limestone.

of the family Brachiopoda, are common to the Magnesian Limestone, Coal, and Primary fossiliferous strata ; but the former has never been met with in any rock above the Magnesian limestone,

and the *Spirifer* very rarely, the only instance known to me being *S. Walcottii* of the Lias. There are certain fish also found, both in England and Germany, in the Lower New Red system, which occur in the Carboniferous strata; but in no formation higher in the series than the Magnesian limestone, not even in the Muschelkalk.

Fig. 293.



Restored outline of a fish of the genus *Palæoniscus*, Agass.*
Magnesian Limestone.

The genus *Palæoniscus*, Agas. (*Palæothrissum*, Blain.) is the most striking example, as three species have been found in England in marl slate, immediately below the Magnesian limestone, and three other different, but nearly allied species, in the slate of the Zechstein of Germany†; and of this genus, which has never yet been met with in rocks of more modern date, there are eight or ten species known in the subjacent Coal. The scales in the species last mentioned are generally smooth, while those in the Magnesian limestone are striated.

* Poissons Fossiles, vol. i. tab. A. fig. 4.

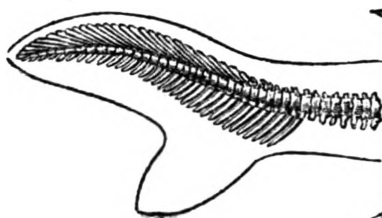
† Sedgwick, Geol. Trans., Second Series, vol. iii. p. 117.

At Tyrone, in Ireland, about three miles east of Dungannon, a deposit of New Red Sandstone occurs, overlying Coal, in which the surface of the beds are often ripple-marked, and in which a small species of *Palæoniscus* (*P. catopterus*, Agas.) occurs in abundance. A slab of this red sandstone now in the museum of the Geological Society of London exhibits, on a surface not exceeding two feet square, more than 250 entire fishes.

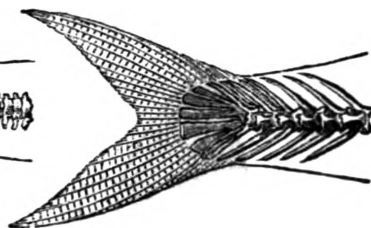
The *Palæoniscus* belongs to that division of fishes which M. Agassiz has called "Heterocercal," which have their tails unequally bilobate, like the recent shark and sturgeon, and the vertebral column running along the upper caudal lobe. (See Fig. 294.) The "Homocercal" fish,

Fig. 294.

Fig. 295.



Shark.
Heterocercal.



Shad. (*Clupea*, Herring tribe.)
Homocercal.

which comprise almost all the 8000 species at present known in the living creation, have the tail-fin either single or equally divided; and the vertebral column stops short, and is not prolonged into either lobe. (See Fig. 295.)

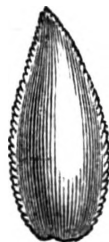
Now it is a singular fact, first pointed out by Agassiz, that the heterocercal form, which is confined to a small number of genera in the existing creation, is universal in the Magnesian limestone, and all the more ancient formations. It characterizes the earlier periods of the earth's history, when the organization of fishes made a greater approach to that of saurian reptiles than at later epochs. In all the strata above the Magnesian limestone the homocercal tail predominates.

The saurians of the period now under consideration (the most ancient examples of fossil reptiles yet known), are all distinguished by having the teeth implanted deeply in the jaw-bone, and in distinct sockets. In the dolomitic conglomerate near Bristol the remains of species of two

Fig. 296.

Tooth of *Palæosaurus platyodon*,
nat. size.

Fig. 297.

Tooth of *Thecodontosaurus*,
3 times magnified.

distinct genera have been found, called *Thecodontosaurus* and *Palæosaurus* by Dr. Riley and

Mr. Stutchbury*; the teeth of which are conical, compressed, and with finely serrated edges.

In the Zechstein of Germany, a rock, as we have seen, of corresponding age, a small saurian reptile, allied, like the former, to the Monitor, has long been known, and has been called *Protosaurus*.

The resemblance before alluded to between the fossils of the Lower New Red system and those of the Coal is not confined to the mollusca and fish, but extends to the Crinoidea, or Stone-lilies. It has even been supposed that some of the species were the same. Thus some specimens, found by Professor Sedgwick in the Magnesian limestone of Durham, were identified by Mr. Miller with *Cyathocrinites planus* (Fig. 320.) of the Mountain limestone of Bristol †; but Mr. Phillips, after comparing these fossils, believes them to be different, those of the Magnesian limestone belonging to *Encrinites moniliformis*.

Origin of the New Red Sandstone group.—The red sandstone and red marl, which, in point of thickness, form the most considerable part both of the upper and lower New Red formation in

* See paper by Messrs. Riley and Stutchbury, Geol. Trans., Second Series, vol. v. p. 349., plate 29., figures 2. and 5.

† Sedgwick, Geological Transactions, Second Series, vol. iii. p. 120.

England and Germany, may have arisen in great part from the disintegration of various crystalline or metamorphic schists; and sometimes, as in parts of Saxony and Devonshire, from porphyritic trap rocks containing much oxide of iron. In some districts of the eastern Grampians in Scotland, as in the north of Forfarshire, the sides of mountains composed of gneiss, mica-schist, and clay-slate, are covered with alluvium, derived from the disintegration of those rocks; and the mass of detritus is stained by oxide of iron, of precisely the same colour as the Old Red Sandstone of the adjoining Lowlands. Now this alluvium merely requires to be swept down to the sea, or into a lake, to form strata of red sandstone and red marl, similar to those of the "Old Red" or New Red system, or those of the Cretaceous era in Spain (see Vol. I. p. 413.), or those of tertiary origin, as at Coudes and Champheix, in Auvergne (see Vol. I. p. 367.), all of which are in lithological characters quite undistinguishable from one another. The pebbles of gneiss in the tertiary red sandstone of Auvergne point clearly to the rocks from which it has been derived. The red colouring matter may have been furnished by the decomposition of hornblende, or mica, which contain oxide of iron in large quantity (see Table at end of Chap. XXVII.).

It is a general fact, and one not yet accounted

for, that scarcely any fossil remains are preserved in stratified rocks in which this oxide of iron abounds; and when we find fossils in the New or Old Red Sandstone in England, it is in the grey, and usually calcareous beds, that they occur.

CHAPTER XXIII.

THE COAL, OR CARBONIFEROUS GROUP.

Carboniferous strata in the south-west of England — Superposition of Coal-measures to mountain limestone — Departure from this type in north of England and Scotland — Freshwater strata — Intermixture of freshwater and marine beds — Sauroidal fish — Fossil plants — Ferns and Sigillariæ — Lepidodendra and Lepidostrobus — Calamites — Coniferæ — Stigmaria.

THE next group which we meet with in the descending order is the Carboniferous, commonly called "The Coal;" because many beds of that mineral, in a more or less pure state, are interstratified with sandstone, shale, and limestone, of which the bulk of the formation is made up. The combustible coal itself, even in Great Britain and Belgium, where it is most abundant, constitutes but a small proportion of the whole mass. In the north of England, for example, the thickness of the coal-bearing strata has been estimated at 3000 feet, while the various coal-seams, 20 or 30 in number, do not exceed 60 feet.*

* Phillips; art. "Geology," Encyc. Britan.

In the south-west of England, in Somersetshire, and in South Wales, the Carboniferous series consists of,

- | | | |
|--|---|---|
| 1st, Coal measures. | { | Strata of shale, sandstone, and grit, with occasional seams of coal, sometimes exceeding 600 feet in thickness. |
| 2d, Millstone grit. | { | A coarse quartzose sandstone passing into a conglomerate, sometimes used for millstones; usually devoid of coal; occasionally above 600 feet thick. |
| 3d, Mountain or Carboniferous limestone. | { | A calcareous rock containing marine shells and corals; devoid of coal; thickness variable, sometimes 900 feet. |

Beneath all these is the Old Red Sandstone, which was formerly considered as part of the Carboniferous series; but which, now that its organic remains are better known, appears entitled to rank as a distinct formation.

As we proceed northwards from South Wales and Somersetshire to Yorkshire and the more northern counties, we find the Carboniferous group beginning gradually to assume a new character, there being first a slight intermixture of the Coal-measures and Mountain limestone at their contact, and these alternations taking place afterwards on a still greater scale. The Coal, in Yorkshire, does not cease when we reach the Millstone-grit, although it is there in diminished quantity; and beneath that grit is a complex deposit, 1000 feet thick, of limestones, alternating with coal-bearing sandstones and shale, below

which comes the great mass of Mountain limestone.* In Scotland we observe a still wider departure from the type of the south of England, the mixture of marine limestone with sandstone and shale containing coal being more complete.

The importance of the coal in England, considered economically, is greatly enhanced by the rich beds of iron-ore which occur in the associated shales and the contiguity of the mountain limestone, which is required as a flux to reduce the iron-ore to a metallic state.†

It is now generally admitted that all coal is of vegetable origin, the vegetable structure being still recognizable in many kinds of coal, when slices thin enough to transmit light are obtained and examined by the microscope. Impressions also of plants, together with entire trunks of trees, are frequently met with in the accompanying shale and sandstone; leaves also, and small branches, and fruits, occur in nodules of clay-ironstone, the inclosed vegetable having served as a nucleus round which the ferruginous matter, usually carbonate of iron, has concreted. Some of the coal-measures are of freshwater origin, and may have been formed in lakes; others seem to have been deposited

* Sedgwick, *Geol. Trans.*, Second Series, vol. iv.; and Phillips, *Geol. of Yorksh.* part 2.

† Conybeare, *Outlines, &c.*, p. 333.

in estuaries, or at the mouths of rivers, in spaces alternately occupied by fresh and salt water.

Thus a freshwater deposit, near Shrewsbury, has been ascertained by Mr. Murchison to be the youngest member of the carboniferous series of that district, at the point where the Coal-measures pass into the lower New Red formation. It consists of shales and sandstones about 150 feet thick, with coal, and traces of plants ; including a bed of limestone, varying from two to nine feet in thickness, which is cellular, and resembles the lacustrine limestone of France and Germany. It has been traced for 30 miles in a straight line, and recognized at more distant points. The characteristic fossils are a small bivalve, having the form of a *Cyclas*, a small

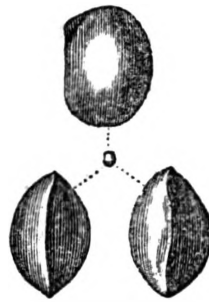
Fresh-water fossils. — Coal.

Fig. 298.



a. *Microconchus carbonarius*.
b. var. of same ; nat. size, and magnified.

Fig. 299.



Cypris inflata, natural size, and magnified. Murchison.*

Cypris (Fig. 299.), and a microscopic shell (*Microconchus*) of an extinct genus.

* Silurian System, p. 84.

But in the lower coal-measures of Coalbrook Dale, the strata, according to Mr. Prestwich, often change completely within very short distances, beds of sandstone passing horizontally into clay, and clay into sandstone. The coal-seams often wedge out or disappear ; and sections, at places nearly contiguous, present marked lithological distinctions. In this single field, in which the strata are from 700 to 800 feet thick, between 40 and 50 species of terrestrial plants have been discovered, besides several fishes and trilobites ; the latter distinct in form from those occurring in the Silurian strata. Also upwards of 40 species of mollusca, among which are two or three of the fresh-water genus *Unio*, and others of marine forms, such as *Nautilus*, *Orthoceras*, *Spirifer*, and *Productus*. Mr. Prestwich suggests that the intermixture of beds containing fresh-water shells with others full of marine remains, and the alternation of coarse sandstone and conglomerate with beds of fine clay or shale containing the remains of plants, may be explained by supposing that the deposit of Coalbrook Dale originated in a bay of the sea or estuary into which flowed a considerable river subject to occasional freshes.*

In the Edinburgh coal-field, at Burdiehouse,

* Prestwich, Geol. Trans., 2d Series, vol. v. p. 440. Murchison, Silurian System, p. 105.

fossil fishes, mollusca and cypris, very similar to those in Shropshire and Staffordshire, have been found by Dr. Hibbert.* In the coal-field also of Yorkshire there are freshwater strata, some of which contain shells referred to the genus *Unio*; but in the midst of the series there is one thin but very widely spread stratum, abounding in fishes and marine shells, such as *Ammonites Listeri* (Fig. 300.), *Orthoceras*, and *Avicula papyracea*, Goldf. (Fig. 301.†)

Fig. 300.

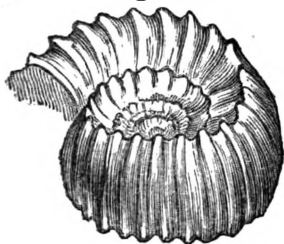
*Ammonites Listeri*, Sow.

Fig. 301.

*Avicula papyracea*, Goldf.
(*Pecten papyraceus*, Sow.)

No similarly intercalated layer of marine shells has been noticed in the neighbouring coal-field of Newcastle, where, as in South Wales and Somersetshire, the marine deposits are entirely below those containing terrestrial and freshwater remains.‡

No bones of mammalia or reptiles have as yet

* Trans. Roy. Soc. Edin., vol. xiii. Horner, Edin. New Phil. Journ., April, 1836.

† Phillips; art. "Geology," Encyc. Metrop., p. 590.

‡ Ibid., p. 592.

been discovered in strata of the carboniferous group. The fish are numerous, and for the most part very remote in their organization from those now living, as they belong chiefly to the Sauroid family of Agassiz; as *Megalichthys Holoptychus* and others, which are often of great size, and all predaceous. Their osteology, says M. Agassiz,

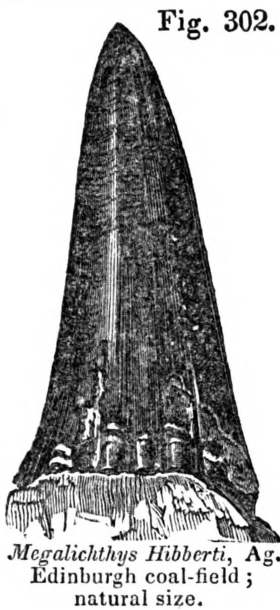


Fig. 302. reminds us in many respects of the skeletons of saurian reptiles, both by the close sutures of the bones of the skull, their large conical teeth striated longitudinally (see Fig. 302.), the articulations of the spinous processes with the vertebræ, and other characters. Yet they do not form a family intermediate between fish and reptiles, but are true *fish*.*

The annexed figure represents a large tooth of the *Megalichthys*, found by Mr. Horner in the Cannel coal of Fifeshire. It probably inhabited an estuary, frequenting both the mouths of rivers and the sea.

Fossil Plants of the Coal.—But the flora of the coal forms the most interesting feature in its palæontology, and is far better known to us than

* Agassiz, Poiss. Foss., livr. 4. p. 63. and livr. 5. p. 88.

any other flora antecedent to the tertiary era. About 300 species of terrestrial plants are enumerated by M. Adolphe Brongniart as proper to the Coal ; but botanists have encountered the greatest difficulty in determining the natural affinities of these fossils, it being rare to find in them any vestige of flower, seed, or fruit, those organs which afford the most convenient characters for classifying living plants. They have been obliged, therefore, first to study more minutely the different forms of bark in existing trees, their various modes of branching, the tissue of their wood, nervures of the leaves, and other peculiarities of vegetable structure which might enable them to institute a direct comparison between the analogous parts of recent and fossil plants.*

The most common of these vegetable remains may be provisionally classed under the following heads :—First, Ferns and *Sigillariæ* ; secondly, *Lepidodendra*, allied to *Lycopodiaceæ* ? thirdly, *Calamites*, allied to *Equisetaceæ* ? fourthly, Coniferous plants ; fifthly, *Stigmaria*, apparently an extinct family of plants.

Ferns and Sigillariæ.—The leaves, or more properly speaking the fronds of ferns (see Figs.

* See the works of MM. Ad. Brongniart, Sternberg, and others, and the Fossil Flora of Lindley and Hutton.

303, 304.), for the most part destitute of fructification, exceed in number all other plants in the shale of the coal. They have been divided by M. Ad. Brongniart into genera, characterized chiefly by the branching of the fronds, and the way in which the veins of the leaves are disposed. These fronds are often accompanied by

Fig. 303.

Fig. 304.



Pecopteris lonchitica.
(Foss. Flo. 153.)



a. Sphenopteris crenata.
b. The same magnified.
(Foss. Flo. 101.)

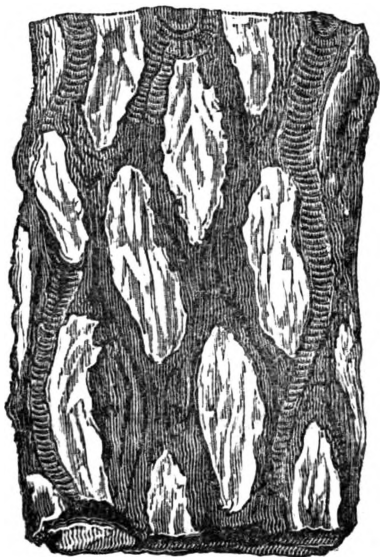
large fluted stems or trunks of trees which have been squeezed down and flattened as they lay prostrate in the shale, so that the opposite sides meet, but which when they occur in the accompanying grit or sandstone, and are placed ob-

liquely or vertically to the planes of stratification, are round and uncompressed. Their bark has been converted into coal; and they must have been hollow when first deposited, for the interior became filled, not only with sand, but with leaves and branches of ferns, introduced from above. Impressions of these fronds are now frequent in the pillars of sandstone, which may be regarded as casts of the interior of those ancient trees. Most of the trunks or stems now alluded to have been called *Sigillariæ*. They vary from half a foot to five feet in diameter, and must have been sometimes forty or fifty feet high.

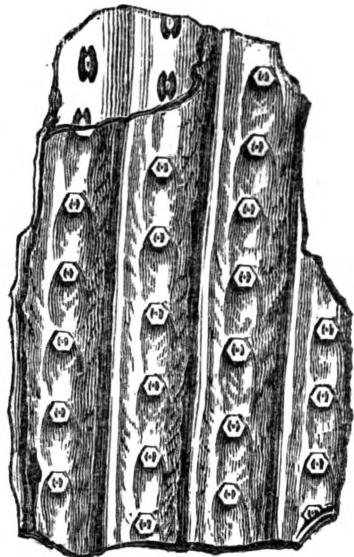
It is admitted by all botanists that some of these gigantic stems, all of which are comprehended by Brongniart in his genus *Sigillaria*, were true

Fig. 305.

Fig. 306.



Sigillaria Lindleyi, Brong.
(*Caulopteris primæva*, Lindley.)



Sigillaria levigata, Brong.

arborescent ferns; as, for example, that section which has been named *Caulopteris* by Lindley and Hutton. (See Fig. 305.) But these are comparatively rare, whereas of the other section (Fig. 306.) more than forty species have been described. In these the scars on the stem are smaller and more regularly arranged in parallel series on the fluted bark (Fig. 306.).

The recent tree-ferns belong to one tribe (*Polypodiaceæ*), and to a small number only of genera in that tribe, in all of which the surface of the trunk is marked with scars, or cicatrices, left after

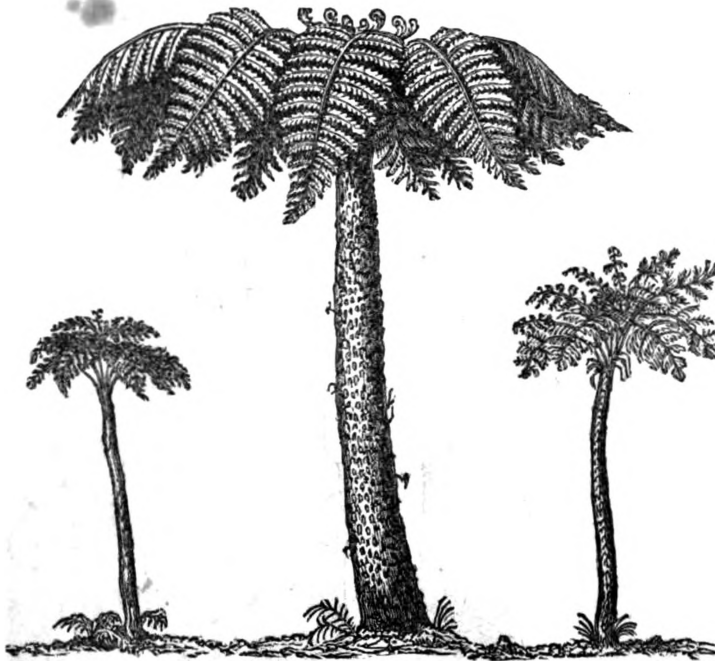


Fig. 307.

Fig. 308.

Fig. 309.

Living Tree Ferns of different Genera. (Ad. Brong.)

Fig. 307. Tree-fern from Isle of Bourbon.

Fig. 308. *Cyathea glauca*, Mauritius.

Fig. 309. Tree-fern from Brazil.

the fall of the fronds. These scars are precisely similar to those of *Caulopteris* (Fig. 305.); but Mr. Lindley objects to the opinion that the remaining *Sigillariæ* of Brongniart were Tree-ferns, because the scars in these are smaller, dissimilar in form, and more regularly arranged in parallel lines; also, because the stems are fluted (see Fig. 306.), and sometimes bifurcating. M. Brongniart has replied, that the forking of the stems of some of the fossil trees is no more than might have been expected from their large size; and as to the forms of the discs or scars from which the fronds have fallen, their individual variations are not greater than those which we find in the fronds of different genera of living ferns, which do not in the present state of the globe attain the size of trees.

Lepidodendra.—Another class of fossils, very common in the coal-shales, have been named *Lepidodendra*. Some of these are of small size, and approach very near in form to the modern *Lycopodiums*, or club-mosses, while others of much larger dimensions are supposed to have been intermediate between these and coniferous plants. The annexed figures represent a large fossil *Lepidodendron*, forty-nine feet long, lately found in Jarrow Colliery, near Newcastle, lying in shale parallel to the planes of stratification. Fragments of others, found in the same shale, indicate by the

size of the rhomboidal scars which cover them a still greater magnitude. The living club-mosses,



Fig. 310.



Fig. 311.



Fig. 312.

Lepidodendron Sternbergii. Coal-measures, near Newcastle.

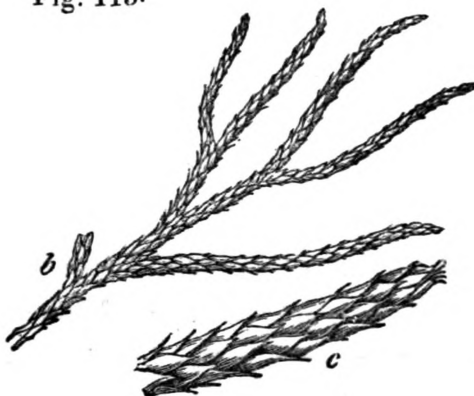
Fig. 310. Branching trunk, 49 feet long, supposed to have belonged to *L. Sternbergii*. (Foss. Flo. 203.)

Fig. 311. Branching stem with bark and leaves of *L. Sternbergii*. (Foss. Flo. 4.)

Fig. 312. Portion of same nearer the root; natural size. (Ibid.)



Fig. 113.



a. *Lycopodium densum*; banks of R. Thames, New Zealand.

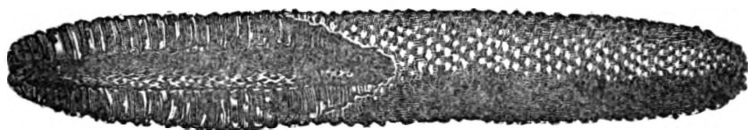
b. branch, natural size.

c. part of same, magnified.

of which there are about 200 species, are abundant in tropical climates, where one species is sometimes met with attaining a height of three feet. They usually creep on the ground, but some stand erect, as the *L. densum*, from New Zealand (Fig. 313.).

In the carboniferous strata of Coalbrook Dale, and in many other coal-fields, elongated cylindrical bodies, called fossil cones, named by M. Adolphe Brongniart *Lepidostrobus*, are met with.

Fig. 314.



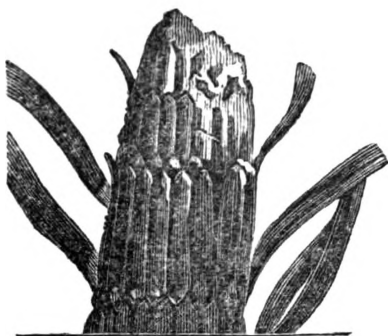
Lepidostrobus ornatus, Brong.; half nat. size. Shropshire.

(See Fig. 314.) They often form the nucleus of concretionary balls of clay-ironstone, and are well preserved, exhibiting a conical axis, around which a great quantity of scales were compactly imbricated. The opinion of M. Brongniart is generally adopted, that the *Lepidostrobus* is the fruit of *Lepidodendron*.

Calamites.—These fossils have a jointed stem longitudinally striated, and are supposed by M. Brongniart to have been allied to the *Equisetaceæ*, or horse-tail tribe; aquatic plants which, in a living state, are only two or three feet high in our climates, and even in tropical countries only attain, as in the case of *Equisetum giganteum*,

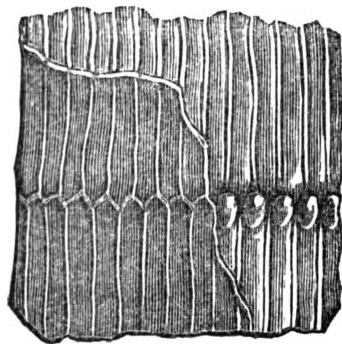
discovered by Humboldt and Bonpland, in South America, a height of about five feet, the stem being an inch in diameter. The *Calamites*, however, of the Coal differed from these principally in being furnished with a thin bark, which is represented in the stem of *C. Suckowii* (Fig. 316.), in which

Fig. 315.



Calamites cannaeformis, Schlöten.
(Foss. Flo. 79.) Common in
English coal.

Fig. 316.



Calamites Suckowii, Brongniart;
natural size. Common in
coal throughout Europe.

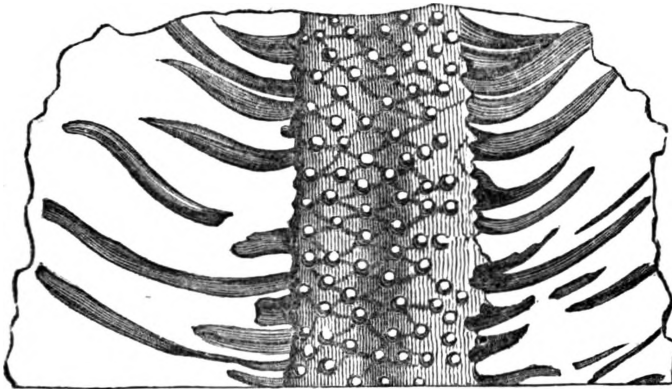
it will be seen that the striped external pattern does not agree with that left on the stone where the bark is stripped off; so that if the two impressions were seen separately, they might be mistaken for two distinct species.

Coniferæ. — The structure of the wood of certain coal plants displays so great an analogy to that of certain pines of the genus *Araucaria*, as to lead to the opinion that some species of firs existed at this period. (See above, p. 85.)

Stigmariæ. — Fragments of a plant which has been called *Stigmaria ficoides* occur in great num-

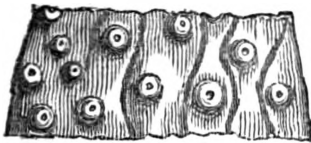
bers in almost every coal-pit. It is supposed to have been a huge succulent water-plant of an extinct family ; thin transparent sections of the stem exhibiting an anatomical structure quite different from the wood of any living tree.* According to

Fig. 317.



Stigmaria ficoides, Brong. One fourth of nat. size. (Foss. Flo. 32.)

Fig. 318.



Surface of another individual of same species, showing form of tubercles. Foss. Flo. 34.)

the conjectures of some botanists, it approached most nearly to the family *Lycopodiaceæ* ; according to others, to *Euphorbiaceæ*.

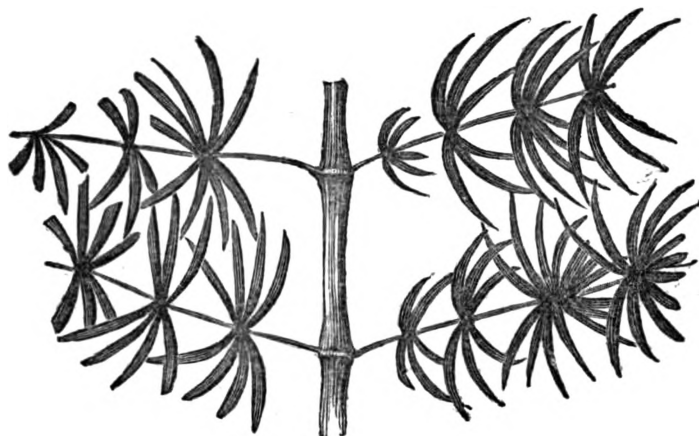
Mr. Hutton discovered one of these *Stigmariæ* forming a huge dome-shaped body, from which twelve branches spread horizontally in all directions, each, usually dividing into two arms, from twenty to thirty feet long, to which leaves of great length were attached. Dr. Buckland im-

* Lindley, Foss. Flora, p. 166.

agines these plants to have grown in swamps, or to have floated in lakes like the modern *Stratiotes*.*

Besides the five classes which have been enumerated, there are other fossil plants, of which the nature is more obscure, and of which no traces have been found among existing vegetables, nor in any strata more recent than the coal. Some of the most abundant of these have been called *Asterophyllites*.

Fig. 319.



Asterophyllites foliosa. (Foss. Flo. 25.) Coal-measures, Newcastle.

I shall postpone some general remarks on the climate of the Carboniferous period, arising out of the contemplation of its flora, until something has been said of the contemporaneous Mountain limestone and its marine fossils.

* Bridgew. Treat., p. 478.

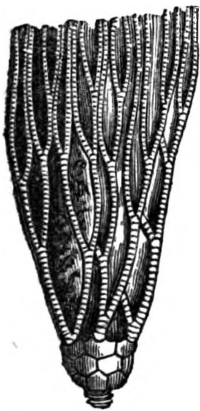
CHAPTER XXIV.

CARBONIFEROUS GROUP *continued.*

Corals and shells of the Mountain limestone — Hot climate of the Carboniferous period inferred from the marine fossils of the Mountain limestone and the plants of the Coal — Origin of the Coal-strata — Contemporaneous freshwater and marine deposits — Modern analogy of strata now in progress in and around New Zealand — Vertical and oblique position of fossil trees in the Coal — How enveloped — How far they prove a rapid rate of deposition.

CARBONIFEROUS or Mountain Limestone.—We have already seen that this rock lies sometimes

Fig. 320.



Cyathocrinites planus,
Miller. Mountain
Limestone.

entirely beneath the Coal-measures, while, in other districts, it alternates with the shales and sandstone of the Coal. In both cases it is destitute of land plants, and usually charged with corals, which are often of large size ; and several species belong to the lamelliferous class of Lamarck, which enter largely into the structure of coral reefs now growing. There

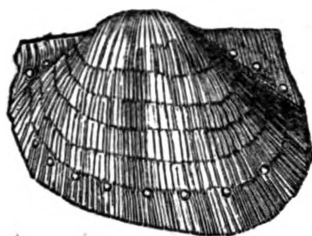
are also a great number of *Crinoidea* (see Fig. 320.), and a few *Echinida*, associated with the zoophytes above mentioned. The *Brachiopoda* constitute a large proportion of the Mollusca, many species being referable to two extinct genera, *Spirifer* (or *Spirifera*, Fig. 321.), and *Producta* (*Leptæna*), Fig. 322.

Fig. 321.



Spirifera glabra, Sow.*
Mountain limestone.

Fig. 322.



Producta Martini, Sow.†
Mountain limestone.

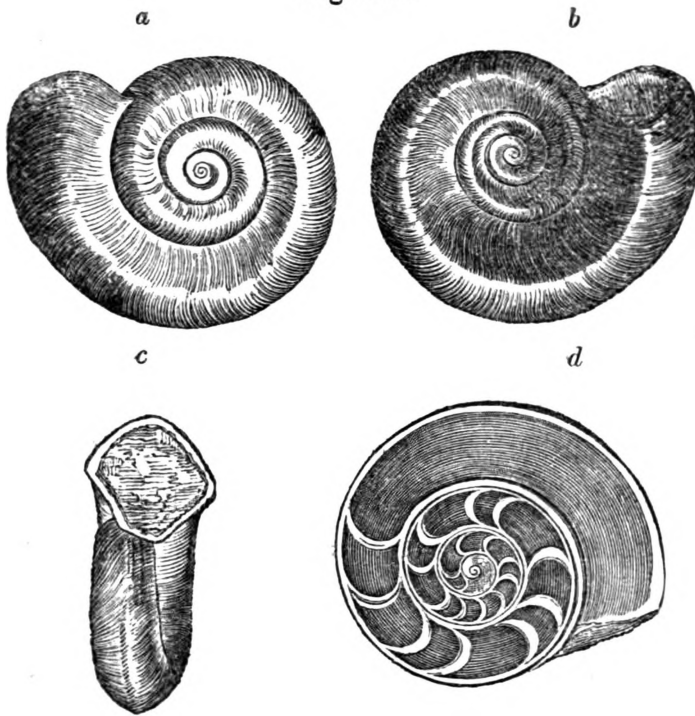
Among the spiral univalve shells the extinct genus *Euomphalus* (see Fig. 323.) is plentifully represented in the fossils of the Mountain limestone. In the interior it is often divided into chambers (see Fig. 323. *d*); the septa or partitions not being perforated, as in foraminiferous shells, or in those having siphuncles, like the *Nautilus*. The animal appears, like the recent *Bulimus decollatus*, to have retreated, at different periods of its growth, from the internal cavity

* Phillips, Geol. of Yorksh., pl. 10. fig. 11.

† Ibid., pl. 8. fig. 19.

previously formed, and to have closed all communication with it by a septum. The number of chambers is irregular, and they are generally wanting in the innermost whorl.

Fig. 323.



Euomphalus pentagulatus, Min. Con. Mountain limestone.

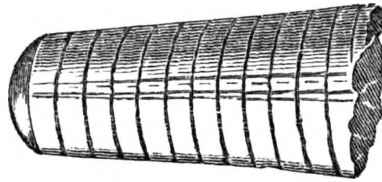
a. upper side; *b.* lower, or umbilical side; *c.* view showing mouth which is less pentagonal in older individuals; *d.* view of polished section, showing internal chambers.

There are also many univalve and bivalve shells of existing genera in the Mountain limestone, such as *Turritella*, *Buccinum*, *Patella*, *Isocardia*, *Nucula*, and *Pecten*.* But the Ce-

* Ibid., vol. ii. p. 208.

phalopoda depart, in general, more widely from living forms, some being generically distinct from all those found in strata newer than the Coal. In this number may be mentioned *Orthoceras*, a siphuncled and chambered shell, like a *Nautilus* uncoiled and straightened. Some species of this genus are several feet long (Fig. 324.). The *Go-*

Fig. 324.



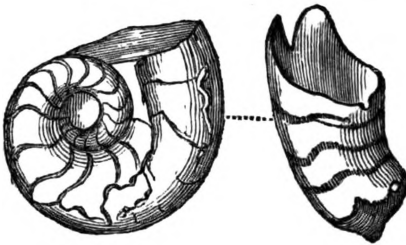
Portion of *Orthoceras laterale*, Phillips. Mountain limestone.

niatite is another genus, nearly allied to the *Ammonite*, from which it differs in having the lobes of the septa free from lateral denticulations, or cre-natures; so that the outline of these is continuous

Fig. 325.

a

Fig. 326.



Goniatites evolutus, Phillips.*
Mountain limestone.



Bellorophon costatus, Sow.†
Mountain limestone.

and uninterrupted (see *a*, Fig. 325.). Their siphon is small, and in the form of the striæ of

* Phillips, Geol. of Yorksh., pl. 20. fig. 65.

† Ibid., pl. 17. fig. 15.

growth they resemble *Nautili*. Another extinct generic form of Cephalopod, abounding in the Mountain limestone, and not found in strata of later date, is the *Bellerophon* (Fig. 326.), of which the shell, like the living Argonaut, was without chambers.

Climate of the Carboniferous period. — The abundance of lamelliferous and other corals, of large chambered Cephalopods and Crinoidea, naturally leads us to infer that the waters of the sea, at this period, were of a far warmer and more equable temperature than is now experienced in those latitudes where the coal strata abound, in Europe. M. Adolphe Brongniart has been led to a similar conclusion in regard to the temperature of the air, from considering the Carboniferous flora. The unquestioned existence of large tree-ferns, such as *Caulopteris* (Fig. 305.), now exclusively the inhabitants of hot and humid climates, and the great variety of fossil fronds of ferns in the Coal confirm this idea, even if we refuse to accede to the arguments adduced to prove that *Sigillariæ* were tree-ferns of extinct genera. The same views receive farther countenance, if the *Lepidodendra* and *Calamites* are rightly conjectured to have been gigantic plants of the orders *Lycopodiaceæ* and *Equisetaceæ*, which, although most largely developed at present in the tropical zone, are

even there of pigmy stature, in comparison with the fossil tribes just alluded to. The *Araucaria*, also, is a family of pines now met with in temperate and warm latitudes; and the fir trees proper to the forests of arctic regions do not appear to have any fossil representatives in the Coal. M. Ad. Brongniart, when endeavouring to establish the great heat and moisture of the climate of the era under consideration, may perhaps have relied too much on the numerical preponderance of ferns over other orders of coal-plants. We may easily be deceived by such reasoning, because it is founded on negative facts, or the absence of plants of certain orders, families, and genera. On this subject Professor Lindley has observed, that the small variety in the forms of each fossil flora must, in a great degree, depend on the relative destructibility of plants when suspended in water before they are imbedded in strata. In illustration of this point, he threw into a vessel containing fresh water 177 plants, among which were species of all the orders found in the Carboniferous flora, with others representing the remaining families and natural orders in the living creation, and found that, at the end of two years, all had decayed and disappeared except the ferns, palms, *Lycopodiaceæ*, and *Coniferæ*. The fructification of the ferns had also vanished, but the form and nervures of the leaves remained.*

* Lindley, Foss, Flora. part 17.

No inference, however, drawn from this experiment, can entirely explain away the fact of the vast preponderance in the coal-shales, of fern-leaves over those of Dicotyledonous plants. Impressions of these last, together with their wood, are plentifully preserved in tertiary rocks in which fossil ferns are rare ; and had they been drifted down in as large numbers as ferns into the estuaries of the Carboniferous period, they would have left impressions of their shape in shale and sandstone, as they have done in more recent formations.

It would, moreover, be rash to assume that the coal-plants in general floated about in water for a year or two before they were enveloped in sediment. It is more probable that a large part of them were deposited immediately with the mud and sand swept down with them by rivers into lakes or the sea. This must have happened in those rare cases where the ferns still retain their fructification. Where this has disappeared, its decomposition may often have been subsequent to the inclosure of the frond in mud or sand.

Origin of the Coal strata. — It has been already shown (pp. 107, 108.) that, in some parts of England, as in Shropshire, certain Coal-measures consist of freshwater strata, and may have originated in a lake ; while others, not far distant, were deposited in estuaries to which the sea

obtained access occasionally ; while a third class were formed at the bottom of an open sea, or in bays of salt water, into which land plants were drifted.

The minor repetitions of alternate fresh and saltwater strata in the Coal, have been ascribed to such changes as may annually occur near the mouths of rivers ; but when shale and grit, containing coal and freshwater shells, are covered by large masses of coralline rock, such as the Mountain limestone, and this again by other Coal-measures, we must suppose great movements of elevation and subsidence, like those by which I endeavoured to explain, in Chapters XVIII. and XX., the superposition of the Cretaceous group to the Wealden, or the alternations of argillaceous and calcareous rocks in the Oolite.

If the superposition, on a great scale, of purely marine strata to others containing Coal and freshwater shells leads us to infer that large areas, once constituting estuaries, deltas, and marshes, sank down and became sea during the carboniferous period, so are there reasons for concluding that in many cases the depression of the ground took place gradually, and that, in consequence of the deposition of sediment, the same space was again and again converted into land, and laid under water. And here I may observe, that two opposite theories have been advanced respecting the pro-

bable manner in which beds of coal were formed ; according to one, the vegetables grew upon the strata now lying immediately beneath them ; according to the other, they were drifted by rivers and marine currents to the situations where we now find them. It can no longer be doubted that both these opinions are true, if we confine our attention to particular places. " Some of the plants of our coal," says Dr. Buckland, " grew on the identical banks of sand, silt, and mud, which, being now indurated to stone and shale, form the strata that accompany the coal ; whilst other portions of these plants have been drifted to various distances from the swamps, savannahs, and forests that gave them birth, particularly those that are dispersed through the sandstones, or mixed with fishes in the shale beds." " At Balgray, three miles north of Glasgow," says the same author, " I saw, in the year 1824, as there still may be seen, an unequivocal example of the stumps of several stems of large trees standing close together in their native place, in a quarry of sandstone of the coal formation."*

Between the years 1837 and 1840, six fossil trees were discovered in the coal-field of Lancashire, where it is intersected by the Bolton railway. They are all in a vertical position, with

* Anniv. Address to Geol. Soc., 1840.

respect to the plane of the bed, which dips about 15° to the south. The distance between the first and the last is more than 100 feet, and the roots of all are imbedded in a soft argillaceous shale. In the same plane with the roots is a bed of coal, eight or ten inches thick, which has been ascertained to extend across the railway, or to the distance of at least ten yards. Just above the covering of the roots, yet beneath the coal seam, so large a quantity of the *Lepidostrobus variabilis* was discovered inclosed in nodules of hard clay, that more than a bushel was collected from the small openings around the base of the trees (see figure of this genus, p. 117.). The exterior trunk of each was marked by a coating of friable coal, varying from one quarter to three quarters of an inch in thickness; but it crumbled away on removing the matrix. The dimensions of one of the trees is $15\frac{1}{2}$ feet in circumference at the base, $7\frac{1}{2}$ feet at the top, its height being 11 feet. All the trees have large spreading roots, solid and strong, sometimes branching, and traced to a distance of several feet, and presumed to extend much farther. Mr. Hawkshaw, who has described these fossils, thinks that, although they were hollow when submerged, they may have consisted originally of hard wood throughout; for solid dicotyledonous trees, when prostrated in tropical forests, as in Venezuela, on the shore of the Carribbean Sea, were observed by

him to be destroyed in the interior, so that little more is left than an outer shell, consisting chiefly of the bark. This decay, he says, goes on most rapidly in low and flat tracts, in which there is a deep rich soil and excessive moisture, supporting tall forest-trees and large palms, below which bamboos, canes, and minor palms flourish luxuriantly. Such tracts, from their lowness, would be most easily submerged, and their dense vegetation might then give rise to a seam of coal.*

If from the upright position of the trees before mentioned, in Lancashire, the spreading of their roots into the shale below, and the layer of coal extending from their base, we infer that they flourished on the spots where they afterwards became fossil, we are also led by other facts lately brought to light in the South Wales coal-field, to believe that the same area was repeatedly submerged, and then again converted, first into marshy, and then dry land. Thus, for example, Mr. Logan has ascertained, that immediately below every regular seam of coal, of which nearly 100 are known in South Wales, lies a bed of clay, varying in thickness from 6 inches to more than 10 feet, called "the under-clay." It is so constant, that the collier regards it as an essential accompaniment of the coal: although always argilla-

* Hawkshaw, Geol. Soc. Proceedings, Nos. 64. and 69.

ceous, it is never without a considerable admixture of sand, and is occasionally quite black, in consequence of the presence of carbonaceous matter. These strata of clay are most strongly marked by containing *Stigmaria ficoides* (Fig. 317.p.119.) in great numbers; the stems of which are usually of considerable length, lying parallel to the plane of the bed, and nearer to the top than the bottom. In diameter they vary from two to six inches, and they are occasionally compressed. Their long slender processes, covered with a pellicle of carbonaceous matter, form an entangled mass, and traverse the beds in every direction, vertically, horizontally, and obliquely; but Mr. Logan has never been able to trace them to their termination, though he has followed single processes for considerable distances. Portions of the stem of the *Stigmaria* are found in other parts of the coal-measures, but it is only in the underclay that the fibrous processes are attached to the stem or associated with it.*

When it is considered, that over so large an area as the coal-field of South Wales not a seam has been discovered without an underclay abounding in *Stigmaria*, it is reasonable to conclude that this plant has contributed largely to the formation of coal. It is supposed that it grew in

* Logan, Proceedings Geol. Soc., No. 67.

lakes and marshes, with its roots in the argillaceous mud, until by the accumulation of sediment and vegetable matter the space was turned into land fit for trees and shrubs of other species. By this process, the lowest part of each coal-seam may have been derived from *Stigmaria*, and the higher portions composed of the remains of other vegetables.

In a deep valley near Capel-Coelbren, branching from the higher part of the Swansea valley, four stems of upright *Sigillariæ* were seen, in 1838, piercing through the coal-measures of S. Wales; one of them was 2 feet in diameter, and one 13 feet and a half high, and they were all found to terminate downwards in a bed of coal. "They seem," says Mr. De la Beche, "to have constituted a portion of a subterranean forest at the epoch when the lower carboniferous strata were formed." *

In a colliery near Newcastle, say the authors of the Fossil Flora, a great number of *Sigillarias* were placed in the rock as if they had retained the position in which they grew. Not less than 30, some of them 4 or 5 feet in diameter, were visible within an area of 50 yards square, the interior being sandstone, and the bark having been converted into coal. The roots of one

* Geol. Report on Cornwall, &c. p. 143.

individual were found imbedded in shale ; and the trunk, after maintaining a perpendicular course and circular form, for the height of about 10 feet, was then bent over so as to become horizontal. Here it was distended laterally, and flattened so as to be only one inch thick, the flutings being comparatively distinct.* Such vertical stems are familiar to our miners, under the name of coal-pipes. One of them, 72 feet in length, was discovered, in 1829, near Gosforth, about five miles from Newcastle, in coal-grit, the strata of which it penetrated. The exterior of the trunk was marked at intervals with knots, indicating the points at which branches had shot off. The wood of the interior had been converted into carbonate of lime ; and its structure was beautifully shown by cutting transverse slices, so thin as to be transparent. (See p. 85.)

If we appreciate the full strength of the evidence in favour of continued subsidence in the coal-field of South Wales, we shall be the less surprised to learn that the vertical depth of the superimposed strata is enormous, amounting in some places to no less than 12,000 feet. Nor are other signs wanting of great geological and geographical changes having been brought about during the deposition of this enormous mass of

* Lindley and Hutton, *Foss. Flo.*, part 6. p. 150.

sediment. Thus, for example, boulders of the more ancient rocks of the carboniferous series have been found in some of the upper and newer members of the same formation. Rounded masses of cannel coal six inches long, pebbles of ironstone, and bituminous coal, containing *Sigillaria*, mingled with boulders of granite and mica-slate, are met with in the Pennant grit, a mass of sandstone, 3000 feet thick, which overlies the lower coal measures.* Some portions of these last had therefore been denuded, and probably upraised above the level of the sea before the deposition of the higher members of the series was concluded.

M. Ad. Brongniart, after comparing the phenomena of the ancient Coal and its fossil plants with the great peat-mosses of the present day, states in a memoir published in 1838, that he continues to adhere to the opinions originally advanced by Werner and De Luc, that the vegetation entombed in the Carboniferous strata chiefly grew in the localities where the coal is now found. Certainly we are not entitled to cherish any disinclination to this hypothesis, on the ground of the reiterated depressions of land, which must be assumed, unless we wholly reject the evidence in favour of Mr. Darwin's theory, that all circular coral reefs owe their shape to the gradual subsidence of the ocean's bed, continued

* Logan, Geol. Soc. Proceedings, No. 69.

for ages, and now in progress.* Within the lagoons encircled by these reefs, groves of the cocoanut and other trees have been found submerged after earthquakes in modern times. In like manner, in the year 1819, extensive flats bordering the Indus sank down, and for many years after, vessels were forced through the boughs of the tamarisk trees, still standing erect, and with their roots still fixed in the muddy sediment below.†

But there are many cases where the fossil trees of the coal are in a position either perpendicular or oblique to the planes of stratification, and where, nevertheless, we cannot reconcile the phenomena with the idea of their having grown on the places where they are now buried.

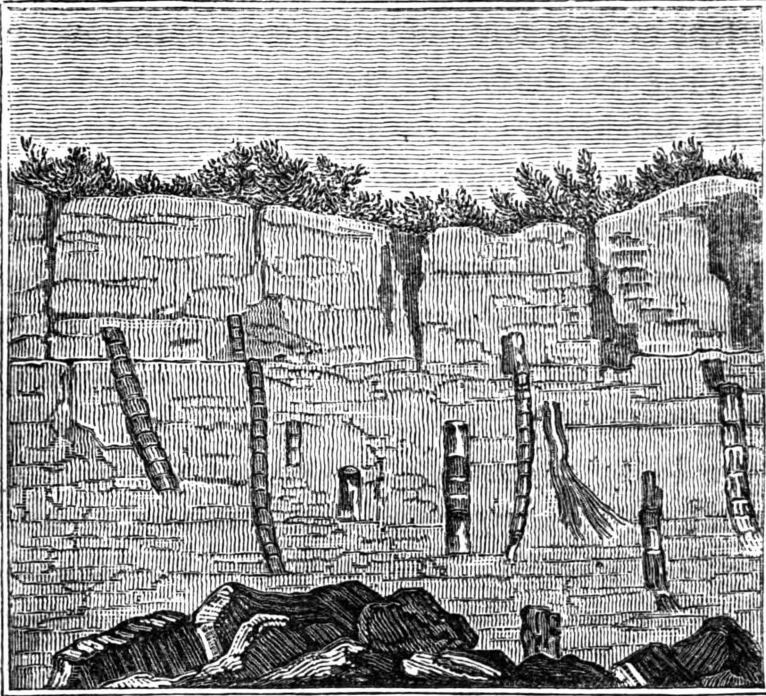
In the account given, in 1821, by M. Alex. Brongniart of the coal-mine of Treuil, at St. Etienne, near Lyons, he states, that distinct horizontal strata of micaceous sandstone are traversed by vertical trunks of Monocotyledonous vegetables, resembling bamboos or large *Equiseta*.‡ Since the consolidation of the stone, there has been here and there a sliding movement which has broken the continuity of the stems, throwing the upper parts of them on one side, so that they are often not continuous with the lower.

* Principles of Geol., vol. iii. 6th ed. "Coral reefs."

† Ibid. "Cutch."

‡ Annales des Mines, 1821.

Fig. 327.



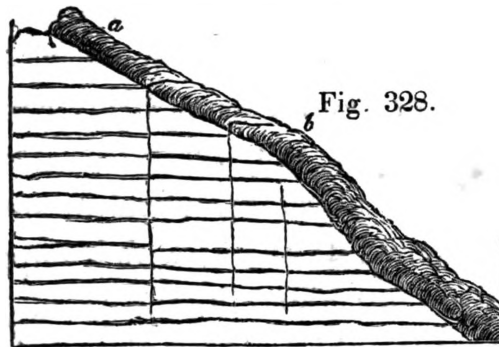
Section showing the erect position of fossil trees in coal sand-stone at St. Etienne. (Alex. Brongniart.)

Although these appearances have been thought to favour the hypothesis of a submerged forest, yet an obvious objection presents itself, that in that case all the roots would have been in the same stratum, or would have been confined to certain levels, and not scattered irregularly through the mass. Besides, when the stems have any roots attached to them, which happens but rarely, they are imbedded in sandstone, precisely similar to that in which the trunks are inclosed ; there being no soil of different composition, like the Portland dirt-bed, — no line of demarcation,

however slight, between the supposed ancient surface of dry land and the sediment now enveloping the trees.

Dr. Buckland informs us that, when he visited these same quarries of Treuil, in 1826, he saw so many trunks in an inclined posture, that the occasional verticality of others might be accidental.* Nevertheless, the possibility of so many of them having remained in an upright posture demands explanation.

In 1830, a slanting trunk was exposed in Craigleith quarry, near Edinburgh, the total length of which exceeded 60 feet. Its diameter at the top was about 7 inches, and near the base it measured 5 feet in its greater, and 2 feet in its lesser width. The bark was converted into a thin coating of the purest and finest coal, forming a striking contrast in colour with the white quartzose sandstone in which it lay. The annexed



Inclined position of a fossil tree, cutting through horizontal beds of sandstone, Craigleith quarry, Edinburgh. Angle of inclination from a to b 27° .

* Bridgew. Treat., p. 471.

figure represents a portion of this tree, about 15 feet long, which I saw exposed in 1830, when all the strata had been removed from one side. The beds which remained were so unaltered and undisturbed at the point of junction, as clearly to show that they had been tranquilly deposited round the tree, and that the tree had not subsequently pierced through them, while they were yet in a soft state. They were composed chiefly of siliceous sandstone, for the most part white; and divided into laminæ so thin, that from six to fourteen of them might be reckoned in the thickness of an inch. Some of these thin layers were dark, and contained coaly matter; but the lowest of the intersected beds were calcareous. The tree could not have been hollow when imbedded, for the interior still preserved the woody texture in a perfect state, the petrifying matter being, for the most part, calcareous.* It is also clear, that the lapidifying matter was not introduced laterally from the strata through which the fossil passes, as most of these were not calcareous. It is well known that, in the Mississippi and other great American rivers, where thousands of trees float annually down the stream, some sink with their roots downwards, and become fixed in the mud. Thus placed, they have been compared to a lance

* See figures of texture, Witham, Foss. Veget., pl. 3.

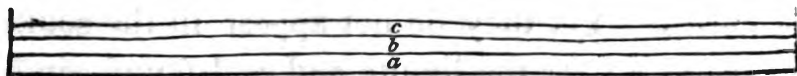
in rest ; and so often do they pierce through the bows of vessels which run against them, that they render the navigation extremely dangerous. But the vertical coal plants did not always retain their roots. Perhaps they sank with their larger end downwards, because the specific gravity of the wood may have been greatest near the lower end. In trees of the Endogenous class, in particular, the wood of the inferior and older part of the trunk is more dense than the upper and younger portions ; and if the former should become water-logged while the upper part of the stem still remained nearly as light as water, or even lighter, not only would the whole trunk descend perpendicularly, but when it reached the bottom it might stand upright, provided a very slight support was afforded to its lower extremity by penetrating to the depth of a foot or two into soft mud. How long such trunks, if constantly submerged, might resist decomposition, is a question which cannot, perhaps, be determined ; but, judging from the duration of wooden piles constantly covered by water, and trees naturally submerged, like those in Louisiana,* we may conclude that they might endure for many years, so that their envelopment in strata, like those of the Coal, may have been effected without a very rapid rate of deposition.

* See Principles, *Index*, "Bistineau."

If, however, we assume that strata 30 or 40 feet thick were often thrown down in a few years, months, or even days, this fact affords no ground for calculating the time required for the formation of a wide coal-field; although it has furnished a popular argument to some writers who desire to prove the earth's crust to be no more than 5000 or 6000 years old. We can by no means presume that all coal-fields were in progress at once, much less that, in the same field, each mass of strata which is parallel, or occupies a corresponding level, was formed simultaneously. It is far more consistent with analogy to suppose that rivers filled up first one part of a fiord, gulf, or bay, nearest the land, and then another; so that the sea was gradually excluded from certain spaces which it previously occupied.

If the structure of a coal-field always resembled that exhibited in the annexed section (Fig. 329.), we might then infer, that if the lowest set of strata, *a*, having a thickness of fifty feet, required half a century for its accumulation, the strata *a*, *b*, *c*, constituting the entire coal-field, and being 150 feet thick, might have been com-

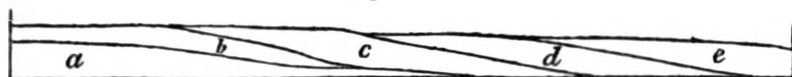
Fig. 329.



pleted in a century and a half. But as the beds are wedge-shaped, and often thin out; and as

the successive beds of a single coal-field are usually arranged in the form of *a, b, c, d, e*, (Fig. 330.), we cannot calculate their number from

Fig. 330.



considering any one section. The deposits, *a, b, c, d, e*, traced in a given direction, may have taken each fifty years for their deposition; but they may have been as limited in breadth as in length. They may have constituted originally a narrow strip of land like part of the delta formed by the Mississippi, since New Orleans was built, by the incessant discharge of mud and drift timber into the Gulf of Mexico. Although by this means a narrow tongue of land has been made to protrude for several leagues into the sea, yet thousands of years may elapse before a square area of low land, having a diameter of as many leagues, can be gained from the Gulf of Mexico.

Detached portions of the ancient Carboniferous group extend from Central Europe to Melville Island and the confines of the arctic region, and have been found, with many of the same plants, in Nova Scotia and the United States of North America. Yet they do not appear in the south of Europe; for the lignite and coal found south of the Alps and Pyrenees, in Spain, Italy, Greece, and other countries bordering the Mediterranean,

seem referable to the Cretaceous and other comparatively modern groups.

In many parts of France and Germany there are isolated patches of Coal strata, entirely free from marine fossils, which repose on granite and other hypogene rocks. They are often confined to an extremely small area, as at St. Etienne, in the department of the Loire ; at Brassac, in that of Puy de Dome ; at Sarrebruck ; also in Silesia, and a hundred other places. All these deposits may have been formed in lakes, existing in the islands of that sea in which the Mountain limestone was formed.*

If the climate of New Zealand and the surrounding ocean was warmer, so that tree-ferns could thrive more luxuriantly on the land, and corals build reefs in the sea, we might conceive new strata to accumulate in that part of the globe, analogous to those of the ancient Coal. The two islands of New Zealand are between 800 and 900 miles in length ; and through the middle of them runs a lofty chain of mountains, said, in some parts, to be 14,000 feet high, and covered with perpetual snow. Many rivers descend from their sides ; and, in the spring, these are copiously charged with sediment, and with abundance of drift wood. Opposite the mouths of these rivers,

* Burat's D'Aubuisson, tom. ii. p. 268.

and near the shores, wherever these may be wasting by the action of the waves, an irregular zone of gravel, sand, and mud must be forming in the surrounding sea—a zone several thousand miles in circumference. No less than 57 species of ferns, some few of them arborescent, have been already discovered in this country ; and what is remarkable, one tree-fern ranges in this country as far south as the 46th degree, south latitude. There are no indigenous mammalia, except one rat, and a species of bat ; few reptiles, and none of large size ; so that we may anticipate a total absence of the bones of land quadrupeds, and a scarcity of those of reptiles, in the modern estuary and lacustrine deposits of this region. That there are lacustrine strata now in progress is certain, since one lake, called Rotorua, in the interior of the northern island, is said to be 40 miles long, and receives the waters of many small rivers and torrents.*

* Account of New Zealand, published for New Zealand Association.

CHAPTER XXV.

OLD RED SANDSTONE, OR DEVONIAN GROUP.

“Old Red” of Scotland, and borders of Wales—Fossils usually rare—Ichthyolites of Caithness—Distinct lithological type of Old Red in Devon and Cornwall—Term “Devonian.”—Organic remains of intermediate character between those of Carboniferous and Silurian systems—Corals and shells—Devonian strata of Westphalia, the Eifel, and Russia.

It was stated in the 22nd chapter that the Carboniferous formation is surmounted by one called the “New Red,” and underlaid by another called the “Old Red Sandstone.” The strata of the last mentioned series have long been recognized in Herefordshire and Scotland as immediately subjacent to the coal, but they are in general so barren of organic remains, that until within the last few years it was difficult to find characters of sufficient importance to distinguish them as an independent group. In Scotland, and on the borders of Wales, the Old Red Sandstone consists chiefly of red arenaceous stone, conglomerate, and shale, with few fossils; but strata of the same age have recently been recognized in Devonshire which wear another lithological aspect, and are peculiarly rich in fossils.

I shall first advert to the more northern type, which is largely developed in Herefordshire, Worcestershire, Shropshire, and South Wales. Its thickness has been estimated by Mr. Murchison at 10,000 feet, and in describing it he adopts the triple subdivision formerly proposed by Messrs. Buckland and Conybeare, namely :—

- 1st. A quartzose conglomerate passing downwards into chocolate-red and green sandstone and marl.
- 2d. Cornstone and marl (red and green argillaceous spotted marls, with irregular courses of impure concretionary limestone, provincially called Cornstone, mottled, red, and green; remains of fishes).
- 3d. Tilestone (finely laminated hard reddish or green micaceous or quartzose sandstones, which split into tiles; remains of mollusca and fishes).

Although here, as usual, fossils are extremely rare in those marls and sandstones in which the red oxide of iron prevails; some remains of fishes of the genera *Cephalaspis* and *Onchus* have been discovered in the Cornstone.* In the grey Tilestones also, *Ichthyodorulites*, of the genus *Onchus*, have been obtained, together with a species of *Dipterus*. With these also have been found some shells referred to the genera *Avicula*, *Arca*, *Cucullæa*, *Terebratula*, *Lingula*, *Turbo*, *Trochus*, *Turritella*, *Bellerophon*, *Orthoceras*, and others.†

* Murchison's Silurian System, p. 180. † Ibid. p. 183.

The whole of the northern part of Scotland, from the southern flank of the Grampians to Cape Wrath, has been well described by Mr. Miller as consisting of a nucleus of granite, gneiss, and other hypogene rocks, which seem as if set in a sandstone frame.* The beds of the Old Red Sandstone constituting this frame may once perhaps have extended continuously over the entire Grampians before the upheaval of that mountain range, for one band of the sandstone follows the course of the Moray Frith far in the interior of the great Caledonian valley; and detached hills and island-like patches occur in several parts of the interior, capping some of the higher summits in Sutherlandshire, and appearing in Murrayshire like oases among the granite rocks of Strathspey. On the western coast of Ross-shire, the Old Red forms those three immense insulated hills before described (p. 140.), where beds of horizontal sandstone, 3000 feet high, rest unconformably on a base of gneiss, attesting the vast denudation which has taken place.

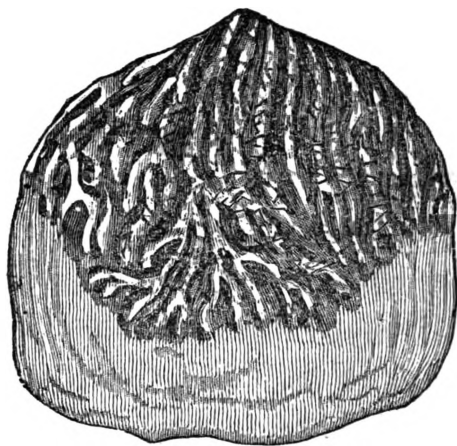
But in order to observe the uppermost part of the Old Red, we must travel south of the Grampians, and examine its junction with the bottom of the Carboniferous series in Fifeshire. This

* The Old Red Sandstone, by Hugh Miller, 1841.

upper member may be seen in Dura Den south of Cupar, to consist of a belt of yellow sandstone, in which Dr. Fleming first discovered scales of *Holoptychus*, and in which lately a species of fish of the genus *Pterichthys* has been met with. (For genus, see Fig. 333.)

The beds next below the yellow sandstone are well seen in the large zone of Old Red which skirts the southern flank of the Grampians from Stonehaven to the Frith of Clyde. It there forms, together with trap, the Sidlaw Hills and the strata of the valley of Strathmore. A section of this region has been already given, extending from the foot of the Grampians in Forfarshire to the sea at Arbroath, a distance of about 20 miles, where the entire mass of strata are several thousand feet thick, and may be divided into three principal masses; 1st, and uppermost, red and mottled marls, cornstone and sandstone (Nos. 1 and 2. of the Section, p. 103.); 2d, Conglomerate, often of vast thickness (No. 3., *ibid.*); 3d, Tilestones and paving stone, highly micaceous, and containing a slight admixture of carbonate of lime (No. 4., *ibid.*). In the first of these divisions a gigantic species of fish of the genus *Holoptychus* has been found at Clashbinnie near Perth. Some scales have been seen which measured 3 inches in length by $2\frac{1}{2}$ in breadth. At the top of the third or lowest

Fig. 331.

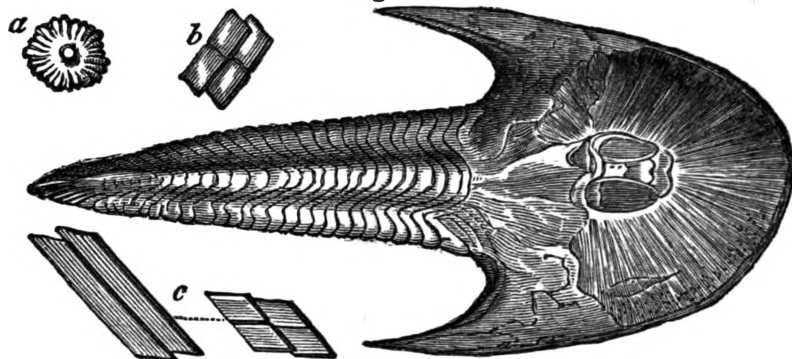


Scale of *Holoptychus nobilissimus*; Agas.
Clashbinnie. nat. size.

division, or immediately under the conglomerate (No. 3. p. 103.), have been found some remarkable crustaceans and fish of the genus named by M. Agassiz, *Cephalaspis*, or "buckler-head -

ed," from the extraordinary shield which covers the head, and which has often been mistaken for that of a trilobite, of the division *Asaphus*. (See Fig. 355. p. 168.)

Fig. 332.



Cephalaspis Lyellii, Agas. Length $6\frac{3}{4}$ inches.

This figure is from a specimen now in my collection, which I procured at Glummiss, in Forfarshire; see other figures, Agassiz, vol. ii. Tab. 1. a. & 1. b.

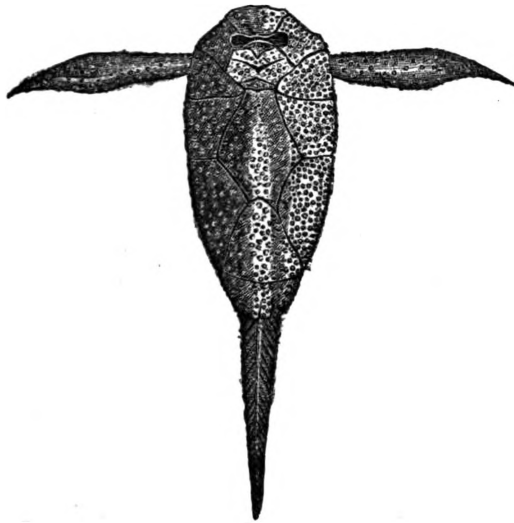
a, one of the peculiar scales with which the head is covered when perfect. These scales are generally removed, as in the specimen above figured.

b, c, scales from different parts of the body and tail.

Species of the same genus are considered in England as characteristic of the second or Cornstone division (p. 146.).

The lower division of the Old Red, abounding in grey slaty sandstones, is most largely developed in the north of Scotland, as in Caithness and Cromarty, where ichthyolites abound. The fish, which are of peculiar forms, belong to the new genera *Pterichthys* (Fig. 333.), *Coccosteus*, *Diplopterus*, *Dipterus*, *Cheiracanthus*, and others of Agassiz.

Fig. 333.



Pterichthys, Agassiz; upper side showing mouth; as restored by H. Miller.*

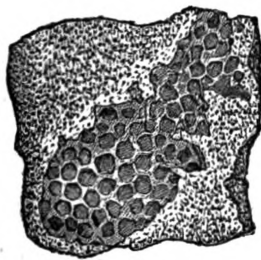
Five species of *Pterichthys* have been found in the lower division of the Old Red. The wing-like appendages, whence the genus is named,

* Plate 1. fig. 1. Mr. M.'s description of the fish is most graphic and correct.

were first supposed by Mr. Miller to be paddles, like those of the turtle ; but Agassiz regards them as weapons of defence, like the occipital spines of the river Bull-head (*Cottus gobio*, Linn.); and considers the tail to have been the only organ of motion. The genera *Dipterus* and *Diplopterus* are so named, because their two dorsal fins are so placed as to front the anal and ventral fins, so as to appear like two pairs of wings. They have boney enamell'd scales.

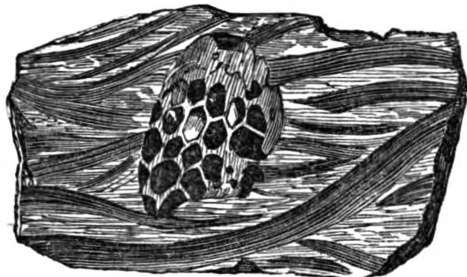
In Forfarshire the lower beds of "the Old Red" are very generally characterized by the remains of what seem to be plants or fucoids ; and these are frequently accompanied, both in the grey sandstones and in the associated shales, with groups of hexagonal, or nearly hexagonal markings, which consist of small flattened carbonaceous bodies, placed in a slight depression of the

Fig. 334.



Eggs of gasteropodous mollusk ?.
Lower beds of Old Red, Ley's
Mill, Forfarshire.

Fig. 335.



*Fucoids and eggs of gasteropodous
mollusk ?.*
Lower Old Red, Fife.

sand or shale. (See Figs. 334. and 335.) They closely resemble in form the spawn of the recent *Natica* (see Fig. 336.), in which the eggs are

Fig. 336.



Fragment of spawn
of British species
of *Natica*.

arranged in a thin layer of sand, and seem to have acquired a polygonal form by pressing against each other. The substance of the egg, if fossilized, might give rise to small pellicles of carbonaceous matter.

These fossils I have met with, both to the north of Strathmore, in the vertical shale beneath the conglomerate, and in the same beds in the Sidlaw hills, at all the points where fig. 4 is introduced in the section, p. 103.

South of Devon and Cornwall. — A great change has lately been effected in the classification of the slaty and calciferous strata of South Devon and Cornwall, a large portion of the beds, formerly referred to the transition or primary fossiliferous series, having been found to belong in reality to the period of the Old Red Sandstone. For this reform we are indebted to the labours of Professor Sedgwick and Mr. Murchison, assisted by a suggestion of Mr. Lonsdale, who, first in 1837, examined the South Devonshire fossils, and perceived that some of them approached to those of the Carboniferous group, others to those of Siluria, while many could not be assigned to either system, the whole taken together exhibiting a peculiar and intermediate character. The true place, however, in the geological series of these slate-rocks and limestones of South Devon could not have been assigned with accuracy, if Messrs.

Sedgwick and Murchison had not previously, in 1836 and 1837, discovered that the culmiferous or anthracitic shales of North Devon belonged to the Coal, and not, as preceding observers had imagined, to the transition period.

As the strata of South Devon now under consideration are far richer in organic remains than the sandstone of contemporaneous date in Herefordshire and Scotland, the new name of the "Devonian system" has been proposed for that of Old Red Sandstone.

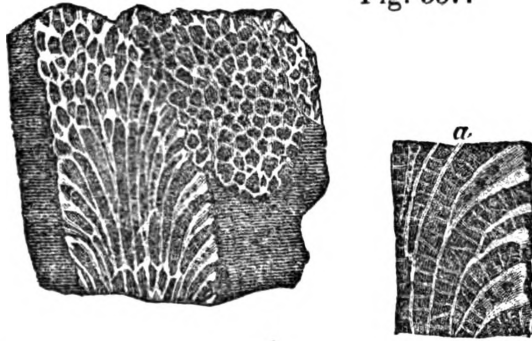
The rocks of this group consist, in great part, of green chloritic slates, alternating with hard quartzose slates and sandstones. Here and there are calcareous slates and some blue crystalline limestone, and in some divisions conglomerates, passing into red sandstone.

The link supplied by the whole assemblage of imbedded fossils, connecting as it does the palæontology of the Silurian and Carboniferous groups, is one of very high theoretical interest, and equally striking, whether we regard the genera of corals or shells. Yet the entire series, taken as a whole, is specifically distinct from the type of fossils of the antecedent or posterior formations.

Among the more abundant corals, we find the genera *Favosites* and *Cyathophyllum*, common on the one hand to the Mountain limestone, and

on the other to the Silurian system. But several even of the *species* are common to the Devonian and Silurian groups (see p. 169.), as for example, *Favosites polymorpha* (Fig. 337.), very abundant in South Devon.

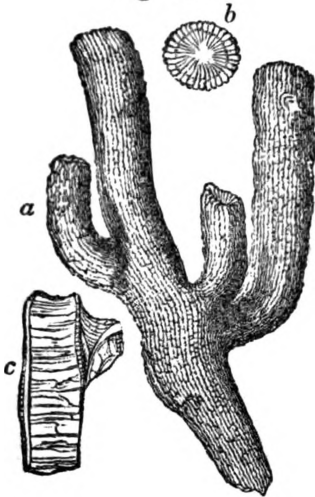
Fig. 337.



Favosites polymorpha, Goldf., S. Devon. From a polished specimen.
a. portion of the same, magnified to show the pores.

The *Cyathophyllum cæspitosum* (Fig. 338.)

Fig. 338.



a. *Cyathophyllum cæspitosum*, Goldf., Plymouth.

b. a terminal star.

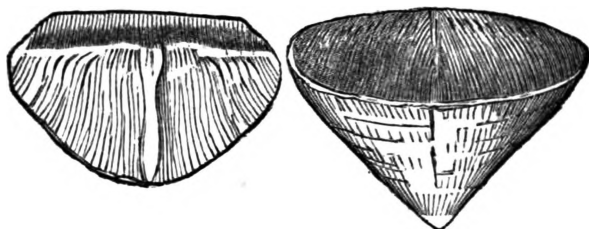
c. vertical section exhibiting transverse plates, and part of another branch.

and *Porites pyriformis* (Fig. 358. p. 169.) are more peculiarly characteristic of the Devonian rocks.

In regard to the shells, all the Brachiopodous genera such as *Terebratula*, *Orthis*, *Spirifer*, *Atrypa*, and *Producta*, which are found in the Mountain Limestone, occur, together with those of the Silurian system, except the *Pentamerus*. Some forms, however, seem exclusively Devonian, as for

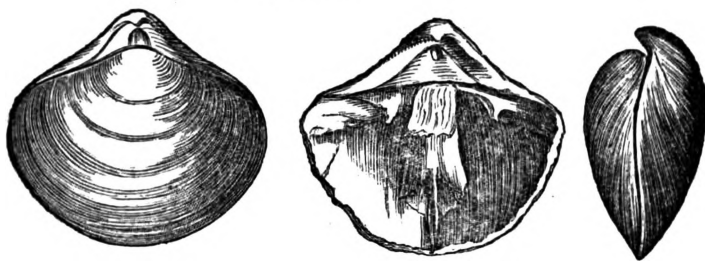
example, *Calceola sandalina* (Fig. 339.) and *Strygocephalus Burtini* (Fig. 340.), which have

b Fig. 339. *a*



Calceola sandalina, Lam. Eifel; also South Devon.
a. both valves united. b. inner side of opercular valve.

a Fig. 340. *c* *b*



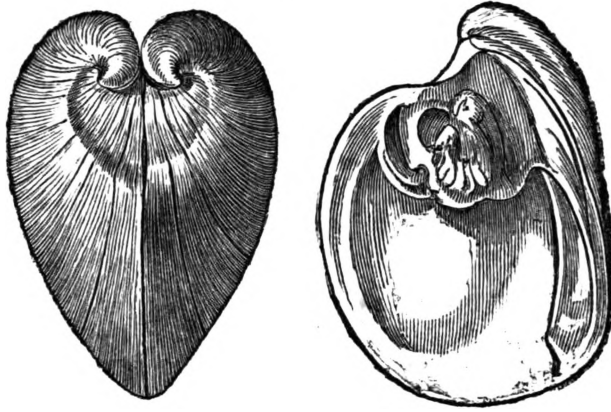
Strygocephalus Burtini. (*Terebratula porrecta*, Sow.) Eifel; also S. Devon.

a. valves united. b. side view of same. c. interior of larger valve, showing thick partition, and thinner one continued from it.

been met with both in the Eifel, in Germany, and in Devonshire, in the very lowest Devonian beds.

Among the peculiar lamelli-branchiate bivalves, also common to Devonshire and the Eifel, we find *Megalodon cucullatus* (Fig. 341.). Several spinal univalves are abundant, among which are two or three species of *Turritella* and *Euomphalus*. Among the Cephalopoda we find *Bellerophon* and *Orthoceras*, as in the Silurian

a Fig. 341. b



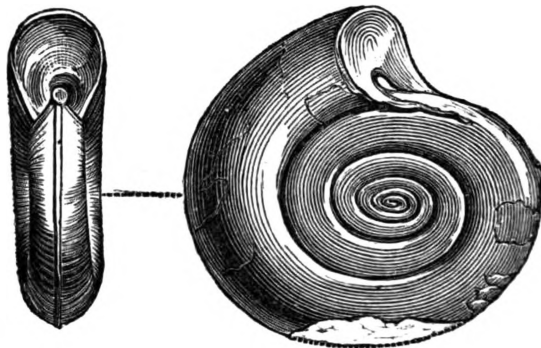
Megalodon cucullatus, Sow. Eifel; also Bradley, S. Devon.

a. the valves united.

b. interior of valve showing the large cardinal tooth.

and Carboniferous groups, and *Goniatite*, as in the Carboniferous. In some of the upper Devonian beds, a shell, resembling a flattened *Goniatite*, occurs, called *Clymenia*, by Munster (*Endosiphonites*, Ansted.*).

Fig. 342.



Clymenia linearis, Munster. (*Endosiphonites carinatus*, Ansted.) Cornwall.

* Camb. Phil. Trans., vol. vi. pl. 8. fig. 2. This shell was figured in the first edition, as a fossil of the Cambrian strata, to which Professor Sedgwick had referred it, before adopting the new classification of the Cornish slates.

A peculiar form of Trilobite, called *Brontes flabellifer* (Fig. 343.), is found in the Devonian strata of the Eifel and in South Devon.

Fig. 343.



Brontes flabellifer, Goldf., Eifel ; also S. Devon.

For determining the true equivalents of the Devonian group in the Rhenish provinces and adjacent parts of Germany, we are indebted to the labours of Professor Sedgwick and Mr. Murchison, in 1839, from which it appears that rocks of that age emerge from beneath the coal-field of Westphalia, and are also found in troughs among the Silurian rocks in Nassau. Many of the limestones, particularly those on the river Lahn, are identical, both in structure and in coralline remains, with the beautiful marbles of Babbacombe, Torquay, and Plymouth.

The limestones of the Eifel, long ago cele-

brated for their fossils, and which lie in a basin supported by Silurian rocks, are found to be referable to the lower part of the Devonian system. In Russia, also, Messrs. Murchison and De Verneuil have shown (1840) that the "Old Red" group occupies a wide area south from St. Petersburg. It was formerly supposed to be the New Red Sandstone, on account of its saliferous and gypseous beds, but it is now proved to be the Old Red by containing ichthyolites of genera which characterize this group in the British Isles, as, for example, *Holoptychus*, *Coccosteus*, *Diplopterus*, &c.*

* See Proceedings of Geol. Soc., and the anniversary speech of Dr. Buckland, P. G. S., for 1841.

CHAPTER XXVI.

PRIMARY FOSSILIFEROUS STRATA.

Primary Fossiliferous or Transition Strata — Term “Grauwacké” — Silurian Group — Upper Silurian and Fossils — Lower Silurian and Fossils — Trilobites — Graptolites — Orthocerata — Occasional horizontality of Silurian Strata — Cambrian Group — Endosiphonite.

WE have now arrived in the descending order at those more ancient sedimentary rocks, which I have called the Primary Fossiliferous (see vol. I. p. 193.), and to which Werner first gave the name of Transition, for reasons fully explained and discussed in the 8th chapter. Many geologists have also applied to these older strata the general name of “*grauwacké*,” by which the German miners designate a variety of quartzose sandstone, or an aggregate of small fragments of quartz, flinty-slate (or Lydian stone), and clay-slate cemented together by argillaceous matter. But by far too much importance has been attached to this kind of rock, as if it were peculiar to a certain epoch in the earth’s history, whereas a similar sandstone or grit is not only found sometimes in the Old Red, and in the millstone grit of the Coal, and in certain Cretaceous formations of the Alps — but even in some tertiary deposits.

In England, the Old Red sandstone has been generally regarded as the base of the secondary

series ; but by some writers on the Continent, the Old Red and Coal formations have been classed as the upper members of the Transition series, an arrangement adopted by Dr. Buckland, in his late Bridgewater Treatise. This classification, however, requires us to draw a strong line of demarcation between the Coal and the lower New Red sandstone group, which now that the fossils of these two groups are ascertained to be very analogous, becomes, perhaps a more arbitrary division than that which separates the Old Red from the uppermost of the primary fossiliferous strata.

Professor Sedgwick and Mr. Murchison have lately proposed to subdivide all the English sedimentary strata below the Old Red sandstone into two leading groups, the upper of which may be termed the Silurian, and the inferior the Cambrian system. Mr. Murchison has applied the name of Silurian to the newer group, because these rocks may be best studied in that part of England and Wales which was included in the ancient British kingdom of the Silures. In his excellent work on the "Silurian System," he has designated the four principal subdivisions of this group as the Ludlow, Wenlock, Caradoc, and Llandeilo rocks, indicating thereby the places where the prevailing characters of each formation are most perfectly exhibited. The following Table explains the succession of these deposits.

UPPER SILURIAN ROCKS.

	Upper Ludlow.	Prevailing Lithological Characters.	Thickness.	Organic Remains.
1. Ludlow formation.	Upper Ludlow.	Micaceous grey sandstone.	2000 Feet.	Mollusca marine, of almost every order, the Brachiopoda most abundant. Serpula, Corals, Sauroid fish, Fuci.
	Aymestry limestone.	Argillaceous limestone.		
	Lower Ludlow.	Shale, with concretions of limestone.		
2. Wenlock formation.	Wenlock limestone.	Concretionary limestone.	1800 Feet.	Marine mollusca of various orders as before. Crustaceans of the Trilobite family. No vertebrata or plants.
	Wenlock shale.	Argillaceous shale.		

LOWER SILURIAN ROCKS.

3. Caradoc formation.	Caradoc sandstones.	Flags of shelly limestone and sandstone, thick bedded white freestone.	2500 Feet.	Crinoidea, Corals, Mollusca, chiefly Brachiopoda, Trilobites.
4. Llandeilo formation.	Llandeilo flags.	Dark coloured calcareous flags.	1200 Feet.	Mollusca, Trilobites.

UPPER SILURIAN ROCKS.

Ludlow formation. — This member of the upper Silurian group, as will be seen by the above table, is of great thickness, and subdivided into three parts. Each of these may be distinguished near the town of Ludlow, and at other places in Shropshire and Herefordshire, by peculiar organic remains.

1. *Upper Ludlow.* — The uppermost division, called the Upper Ludlow, consists of grey calcareous sandstone, decomposing into soft mud, and contains, among other shells, the *Lingula cornea*, which is common to it and the lowest, or tilestone beds of the Old Red. But the *Orthis orbicularis*

Fig. 344.



Orthis orbicularis, J. Sow. Delbury.
(*Strophomene orbicularis*.)

Fig. 345.



Terebratula navicula, J. Sow.
Ludlow; also in Aymestry
limestone.

is peculiar to the Upper Ludlow, and very common; and the lowest or mud-stone beds, are loaded for a thickness of 30 feet with *Terebratula navicula* (Fig. 345.), in vast numbers. Among the cephalopodous mollusca occur the genera *Bellerophon* and *Orthoceras*, and in the crustacea the *Homalonotus* (Fig. 353.). A coral called *Favosites*

polymorpha, Goldf. (Fig. 337. p. 154.) is found both in this subdivision and in the Devonian system. But the most remarkable fossils of this formation are the scales, spines (*Ichthyodorulites*,) jaws, and teeth of fish of the genera *Onchus*, *Plectrodus* and others. As these are the oldest remains of vertebrated animals yet known to geologists, it is worthy of notice that they belong to a family of fishes of a high or very perfect organization.

Among the fossil shells are species of *Producta* (*Leptæna*), *Orthis*, *Terebratula*, *Avicula*, *Trochus*, *Orthoceras*, *Bellerophon*, and others.*

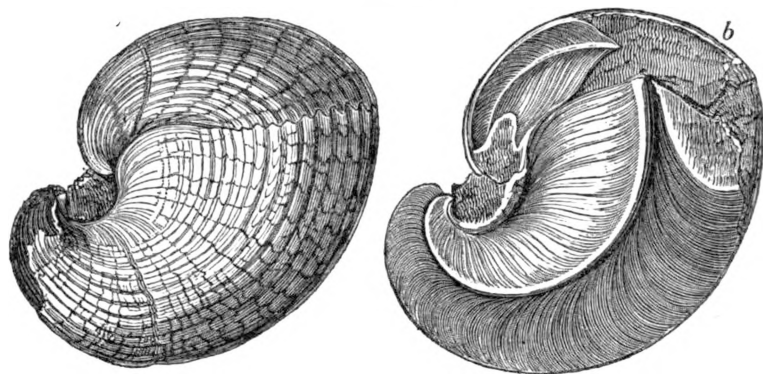
Some of the Upper Ludlow sandstones are ripple-marked, thus affording evidence of gradual deposition ; and the same may be said of the accompanying fine argillaceous shales which are of great thickness, and have been provincially named "mudstones." In these shales many zoophytes are found enveloped in an erect position, having evidently become fossil on the spots where they grew at the bottom of the sea.

The facility with which these rocks, when exposed to the weather, are resolved into mud, proves that notwithstanding their antiquity, they are nearly in the state in which they were first thrown down at the bottom of the sea.

2. *Aymestry limestone*.—The next group is a

* Murchison, Silurian System, p. 198, 199.

subcrystalline and argillaceous limestone, which is in some places 50 feet thick, and distinguished around Aymestry by the abundance of *Pentamerus Knightii*, Sow. (Fig. 346.), also found in the Fig. 346.



Pentamerus Knightii, Sow. Aymestry.

a. view of both valves united.

b. longitudinal section through both valves, showing the central plate or septum ; half nat. size.

Lower Ludlow. This genus of Brachiopoda has only been found in the Silurian strata. The name was derived from $\pi\epsilon\nu\tau\epsilon$, *pente*, five, and $\mu\epsilon\rho\omicron\varsigma$, *meros*, a part, because both valves are divided by a central septum, making four chambers, and in one valve the septum itself contains a small chamber, making five ; but neither the structure of this shell, nor the connection of the animal with its several parts, are as yet understood.

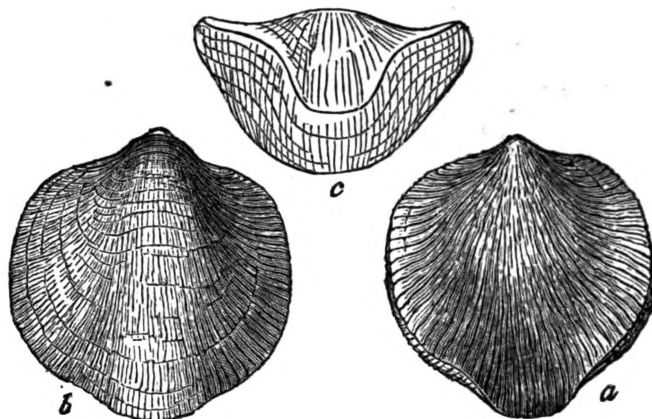
Three other abundant shells in this limestone are, 1st, *Terebratula Wilsoni*, Sow, (Fig. 347.), which is also common to the Lower Ludlow and Wenlock limestone ; 2d, *Atrypa affinis* (Fig. 348.), which has a very wide range, being found

in every part of the Silurian system, except the Llandeilo flags; and 3dly, *Lingula Lewisii* (Fig. 349.).

Fig. 347.

*Terebratula Wilsoni*, Sow. Aymestry.

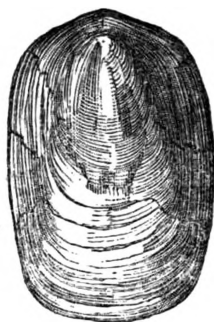
Fig. 348.

*Atrypa affinis*, Sow. (*Terebratula affinis*, Min. Con.) Aymestry.
a. upper valve.

b. lower.

c. anterior margin of the valves.

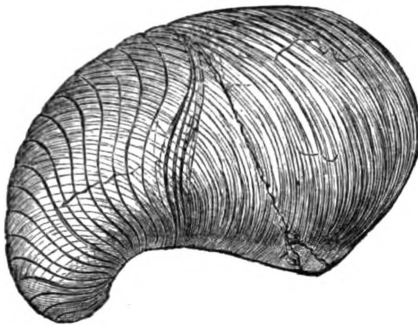
Fig. 349.

*Lingula Lewisii*, J. Sow. Abberley Hills.

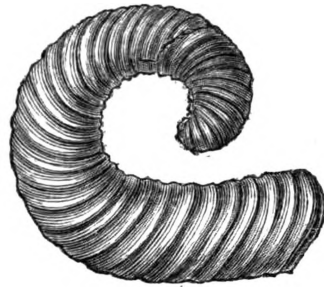
3. *Lower Ludlow shale*.—A dark grey argillaceous deposit, containing, among other fossils, the new genera of chambered shells, *Phragmoceras* and *Lituities* of Broderip. (See Figs. 350, 351.) The latter is partly straight and partly convoluted, nearly as in *Spirula*.

Fig. 350.

Fig. 351.



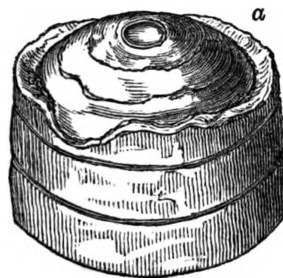
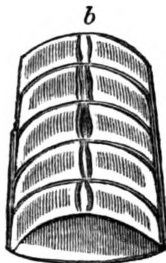
Phragmoceras ventricosum, J. Sow.
(*Orthoceras ventricosum*, Stein.)
Aymestry; $\frac{1}{4}$ nat. size.



Lituities giganteus, J. Sow; near Ludlow;
also in the Aymestry and Wenlock limestones; $\frac{1}{4}$ nat. size.

The *Orthoceras Ludense* (Fig. 352.), as well as the shell last mentioned, is peculiar to this member of the series. The *Homalonotus delphinoce-*

Fig. 352.

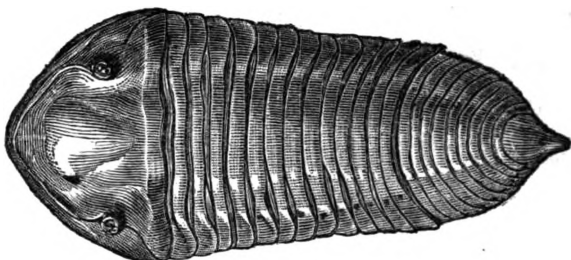


a. fragment of *Orthoceras Ludense*, J. Sow.

b. polished section, showing siphuncle. Ludlow.

phalus (Fig. 353.) is common to this division and to the Wenlock limestone. This crustacean

Fig. 353.



Homalonotus delphinocephalus, König.* Dudley Castle; $\frac{1}{3}$ nat. size.

belongs to a group of trilobites which has been met with in the Silurian rocks only, and in which the tripartite character of the dorsal crust is almost lost.

A species of *Graptolite* (Fig. 364. p. 173.), a genus which has not yet been met with in strata newer than the Silurian, makes its appearance in the Lower Ludlow.

Wenlock formation.— We next come to the Wenlock formation, which has been divided (see Table, p. 161.) into

1. Wenlock limestone, formerly well known to collectors by the name of the Dudley limestone, which forms a continuous ridge, ranging for about 20 miles from S.W. to N. E., about a mile distant from the nearly parallel escarpment of the Aymes-try limestone. The prominence of this rock in

* Silurian System, pl. 7. bis. fig. 1. b.

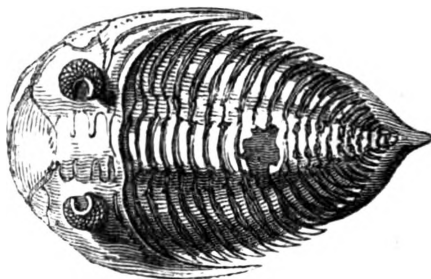
Shropshire, like that of Aymestry, is due to its solidity, and to the softness of the shales above and below. It is divided into large concretionary masses of pure limestone, and abounds in trilobites, among which the prevailing species are *Asaphus caudatus* (Fig. 355.) and *Calymene Blumenbachii*. The latter is often found coiled up like a wood-louse (see Fig. 354.).

Fig. 354.



Calymene Blumenbachii, Brongniart, commonly called "Dudley trilobite." Also in L. Ludlow & Aym. lime.

Fig. 355.



Asaphus caudatus, Brong., Ludlow; also in Aym. lime., L. Ludlow, and Wen. shale.

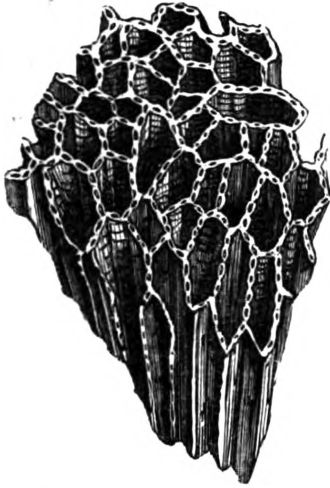
Producta depressa, Sow., is common in this rock, but also ranges through the Lower Ludlow, Wenlock shale, and Caradoc Sandstone.

Fig. 356.



Producta depressa (Syn. *Leptæna depressa*), Wenlock.

Fig. 357.

*Catenipora escharoides.*

Among the corals in which this formation is very rich, the *Catenipora escharoides*, Lam. (Fig. 357.), may be pointed out as one very easily recognized, and widely spread in Europe, and not yet found in any group above the Silurian, through all parts of which it ranges, from the Aymestry limestone to the bottom of the series.

Another coral, the *Porites pyriformis*, is also met with in profusion ; but the same species, as before stated, is common to the Devonian rocks.

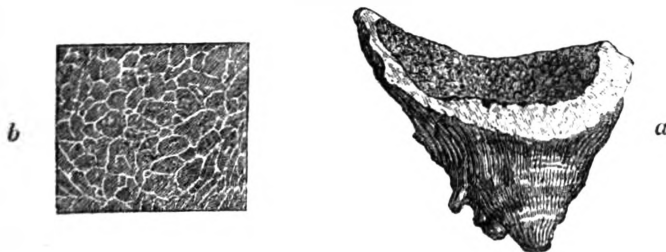
Fig. 358.



Porites pyriformis, Ehren. Wenlock. Also in Aymestry limestone, L. Ludlow, and Wen. shale.

a. Vertical section, showing transverse lamellæ.

Fig. 359.



a. *Cystiphyllum Siluriense*, Lonsd. Wenlock.

b. Section of portion showing cells.

Cystiphyllum Siluriense (Fig. 359.) is a species peculiar to the Wenlock limestone. This new genus, the name of which is derived from *κυστις*, a *bladder*, and *φυλλον*, a *leaf*, was instituted by Mr. Lonsdale for corals of the Silurian and Devonian groups. It is composed of small bladder-like cells (see Fig. 359. *b.*).

2. The Wenlock Shale, which exceeds 700 feet in thickness, contains many species of Brachiopoda, such as a small variety of the *Lingula Lewisii* (Fig. 349.), and the *Atrypa affinis* (Fig. 348.) before mentioned, and it will be seen that several other fossils before enumerated range into this shale.

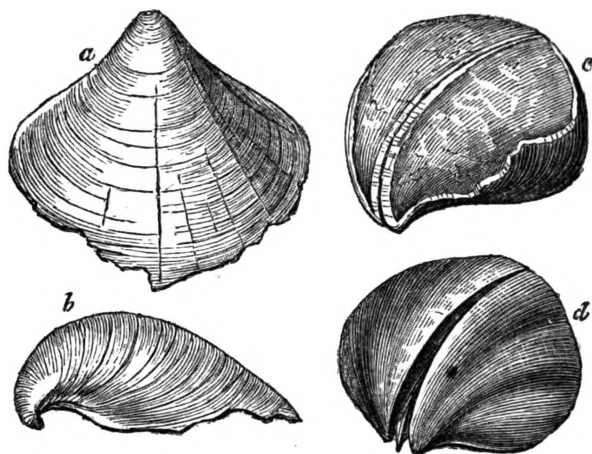
LOWER SILURIAN ROCKS.

The lower Silurian rocks have been subdivided into two portions.

1. The Caradoc sandstone, which abuts against the trappean chain called the Caradoc Hills, in Shropshire. Its thickness is estimated at 2500 ft., and the larger proportion of its fossils are specifically distinct from those of the upper Silurian rocks. Among them we find many trilobites and shells of the genera *Orthoceras*, *Nautilus*, and *Bellerophon*; and among the Brachiopoda the *Pentamerus lævis* (Fig. 360.), which is very abundant and peculiar to this bed; also *Orthis grandis* (Fig. 361.), and a fossil of well-defined form, but of which the class

is not yet determined by zoologists, *Tentaculites scalaris*, Schlot (Fig. 362.).

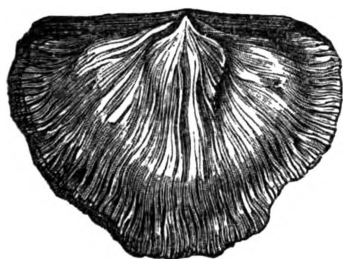
Fig. 360.



Pentamerus laevis, Sow. Caradoc Sandstone.

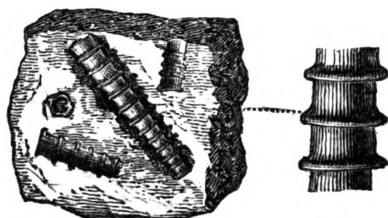
a. b. Views of the shell itself, from figures in Murchison's Sil. Syst. *c.* Cast with portion of shell remaining, and with the hollow of the central septum filled with spar. *d.* Internal cast of a valve, the space once occupied by the septum being represented by a hollow in which is seen a cast of the chamber within the septum.

Fig. 361.



Cast of *Orthis grandis*, J. Sow. Horderley; two thirds of nat. size.

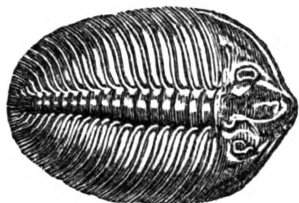
Fig. 362.



Tentaculites scalaris, Schlot. Eastnor Park; nat. size, and magnified.

2. The *Llandeilo flags*, so named from a town in Caermarthenshire, form the base of the Silurian system, consisting of

Fig. 363.



Asaphus Buchii,
Brong. Caermarthen;
 $\frac{1}{4}$ nat. size.

dark-coloured micaceous grit, frequently calcareous, and distinguished by containing the large trilobites *Asaphus Buchii* and *A. tyrannus*, Murch., both of which are

peculiar to these rocks. Several species of Graptolites (Fig. 364.) occur in these beds.

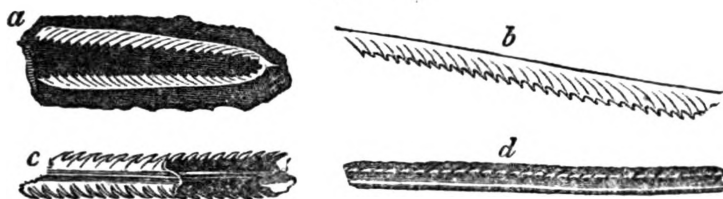
No land plants seem yet to have been discovered in strata which can be unequivocally demonstrated to belong to the Silurian period. But we learn from Mr. Conrad that, in North America, both in the highest and lowest members of the series, marine plants, or fucoids, have been discovered.

From the absence of all terrestrial vegetation and freshwater shells some geologists have inferred that a small extent of dry land existed at the remote periods now under consideration. But if we colour on a map of the globe those spots over which the Silurian strata have been hitherto traced, and consider the insignificance of their extent in comparison with the surface of the planet, we shall perceive the rashness of such generalizations.

In Norway and Sweden the Silurian strata

extend over a wide area, and so much resemble those of England in lithological character and fossils, that they will probably be found to be divisible into similar groups. They are composed of large deposits of sandstone, which is sometimes found at the base of the system, resting on gneiss and calcareous rocks, with orthocerata and corals; the chain-coral (Fig. 357.), before mentioned, being very conspicuous; also fine bituminous shales containing graptolites (Fig. 364.).

Fig. 364.



- a. b. Graptolithus Murchisonii*, Beck; Christiania, Norway;
also in Lower Silurian, England,
c. G. foliaceus, south of Sweden; also Llandeilo flags, England.
d. G. Ludensis, south of Sweden; Upper Silurian, in England.

These bodies, which I collected both in the higher and lower shales of the Silurian system in Sweden and Norway, are supposed by Dr. Beck, of Copenhagen, to be fossil zoophytes, related to the *Pennatula*, of which the living animals inhabit mud and slimy sediment.

In the limestones of Lake Michigan, in North America, examined by Dr. Bigsby, and other

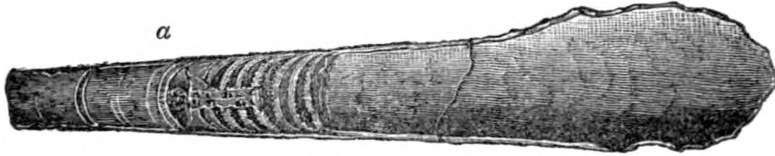
regions bordering the great Canadian lakes, and along the northern coast of the Gulf of St. Lawrence, surveyed by Captain Bayfield, chain-corals and trilobites are also found, and from their fossils generally they have for many years been referred to the transition period. In the state of New York also the labours of Messrs. Hall and Conrad have shown that between Lake Ontario and the Mohawk river the lower Silurian rocks are found ; and further south the upper members of that series appear, being in their turn covered, on the borders of Pennsylvania, by the Old Red Sandstone, containing scales of *Holoptychus*, like those before described. (See Fig. 331. p. 149.)

Certain orthocerata, from Lake Huron, have a very peculiar structure. The siphuncle is very large, and has a tube running through its whole length, from the outside of which radii set off in verticillations extending to the inner wall of the syphon, these verticillations corresponding in number to the chambers of the shell. Mr. Stokes, who has described this division of orthoceratites, has formed them into a distinct genus, for which he has adopted the name of *Actinoceras*, proposed by Professor Bronn.* The *Actinoceras* was not known as a British fossil, until lately discovered in Silurian strata at Castle Espie, in

* See Trans. Geol. Soc., 2d series, vol. v. part 3. p. 708.

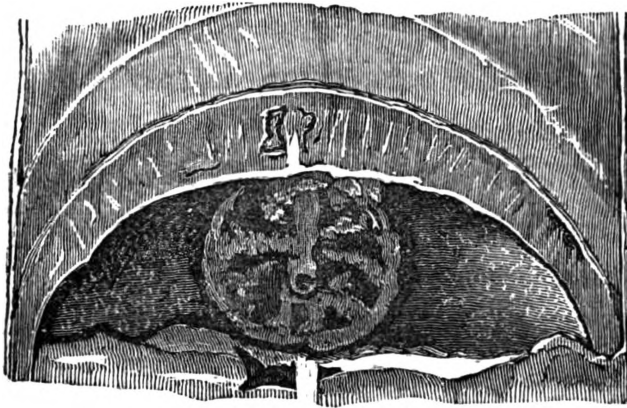
the county of Down, in Ireland. (See Figs. 365, 366.)

Fig. 365.



Actinoceras Simmsii, Stokes.
County of Down, Ireland. Length of original 2 feet.

Fig. 366.



A. Simmsii, portion of the shell at *a*, Fig. 365., natural size, showing the tube and its radii within the siphuncle.

Silurian strata occasionally horizontal.—The Silurian strata throughout a large part of the province of Skaraborg, in the south of Sweden, are perfectly horizontal; the different subordinate formations of sandstone, shale, and limestone, occurring at corresponding heights in hills many leagues distant from each other, with the same mineral characters and organic remains. It is clear that they have never been disturbed since the time of their deposition, ex-

cept by such gradual movements as those by which large areas in Sweden and Greenland are now slowly and insensibly rising above or sinking below their former level. The ancient limestone and shale also of the Canadian lake district and the State of New York, before mentioned, are for the most part horizontal.

These facts are very important, as the more ancient rocks are usually much disturbed, and horizontality is a common character of newer strata. Similar exceptions, however, occur in regard to the more modern or tertiary formations which, in some places, as in the Alps, are not only vertical, but in a reversed position. These appearances accord best with the theory which teaches that, at all periods, some parts of the earth's crust have been convulsed by violent movements, which have been sometimes continued so long, or so often repeated, that the derangement has become excessive; while other spaces have escaped again and again, and have never once been visited by the same kind of movement. Had paroxysmal convulsions ever agitated simultaneously the entire crust of the earth, as some have imagined, the primary fossiliferous strata would nowhere have remained horizontal.

Cambrian Group.—Below the Silurian strata in the region of the Cumberland lakes, in N.

Wales, and other parts of Great Britain, there is a vast thickness of stratified rocks, for the most part slaty and devoid of fossils. In some places a few organic remains are detected, but they are usually obscure ; and whether the species will prove to be sufficiently distinct to entitle the rocks containing them to rank as an independent group, may be doubted. These rocks have been called Cambrian by Professor Sedgwick, because they are largely developed in N. Wales, where they attain a thickness of several thousand yards. They are chiefly formed of slaty sandstone and conglomerate, in the midst of which is a limestone containing shells and corals, as at Bala in Merionethshire. A slaty sandstone, forming the bottom of the Cambrian system in Snowdon, contains shells of the family Brachiopoda, and a few zoophytes.

TABLE

Showing the Order of Superposition, or Chronological Succession, of the principal European Groups of Fossiliferous Strata.

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.		Some of the Localities where the Formation occurs.	
I. Post-Pliocene Period.	A. Recent.	MARINE. (a) Consolidated and sandy beds; (b), hard calcareous sandstones, inclosing corals, shells, pottery, and human skeletons; (c), coral limestone, consisting of corals, shells, &c.	FRESHWATER. (d) Peat, with freshwater shells, bones of land animals, human remains, and works of art; (e) <i>Travertin</i>, calcareous deposits from mineral springs.	a. Newer part of delta of Rhone, in the Mediterranean. b. Shore of Island of Guadaloupe. c. Newer part of coral reefs in Pacific, &c. d. Kinnordy, Forfarshire; Solway Moss. e. Tivoli, and other parts of Italy.
	B. Post-Pliocene.	(a) Clay, sand, and volcanic tuff, with shells of recent species; (b), limestone, with casts of recent shells. <i>Boulder formation</i>, (c.), sand and clay, with erratics.	(d) Sand, clay, and lignites, with shells and fish scales. <i>Shell marl</i> of Scotland (e), with shells and freshwater plants, and masses of solid limestone. <i>Loess of the Rhine</i>. (f) Silt with land and freshwater shells.	a. Ischia. b. Cuba. c. Scandinavia; mud cliffs of Norfolk; and Beaufort, Canada. d. Mundesley. e. Bakie, Forfarshire. f. Valley of Rhine.
	The Post-Pliocene deposits, including the Recent, are for the most part concealed under existing seas and lakes.			

TABLE. — *Continued.*

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.		Some of the Localities where the Formation occurs.
II. TERTIARY PERIOD.	C. Newer Pliocene.	(a) Loam, with marine shells; (b), limestone and calcareous conglomerate. (c) Strata of Loam, sand and gravel, with freshwater shells and bones of extinct quadrupeds. A large majority of the shells of recent species.	a. Glasgow. b. Sicily. c. Brentford, &c., Valley of Thames.
	D. Older Pliocene.	<i>Norwich Crag.</i> — (a) Shelly sand and loam, with marine shells and bones of land animals. <i>Subapennine beds.</i> — (b) Yellow sand and blue clay. (c) Sand, with freshwater shells. Half, or more than half, the shells usually of recent species.	a. Postwick, Norwich. b. Subapennines, Italy. c. Postwick, Norwich.
	E. Miocene.	<i>Red Crag.</i> — (a) Red ferruginous quartzose sand, with rolled shells. <i>Coralline Crag.</i> — (b) White calcareous sand, passing into a soft stone, with minutened coral and shells. <i>Faluns of the Loire.</i> — (c) Similar aggregates and marl. <i>Bordeaux beds.</i> — (d) Argillaceous and marly deposits. (e) Blue clay and yellow sand, with mammalian bones and freshwater shells; (f), beds similar to d, with land and freshwater shells. About one fourth of the species of shells recent.	a. Suffolk. b. Orford, Suffolk. c. Valley of the Loire, near Nantes, Angers, Tours, and Blois. d. Bordeaux and Dax. e. Upper Val d'Arno. f. Saucats, 12 miles south of Bordeaux.
	F. Eocene.	<i>London clay.</i> — (a) Clay and sand. <i>Calcaire grossier.</i> — (b.) Coarse limestone. <i>Calcaire siliceux.</i> — (c.) Siliceous limestone, siliceous millstone, green, white, and gypseous marls and gypsum. Species of shells, almost without exception, extinct.	a. London and Hampshire basins. b. Paris basin. c. Paris basin; Isle of Wight.

TABLE — *continued.*

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. SECONDARY PERIOD.	G. Cretaceous Group.	1. <i>Maestricht Beds.</i> —(a) Soft yellowish-white limestone, resembling chalk, with siliceous masses; (b), aggregate of corals; (c), <i>Baculite limestone</i> (marine).
		a. St. Peter's Mount, Maestricht; Ciply, near Mons.
		b. Faxoe, Denmark.
		c. Valognes, Normandy.
	H. Wealden Group.	2. <i>Chalk with flints</i> (marine).
		3. Chalk without flints, and chalk-marl (marine).
		4. <i>Upper green sand</i> (marine).—Marly stone, and sand with green particles; layers of calcareous sandstone.
		5. <i>Gault</i> (marine).—Blue clay, with numerous fossils, passing into calcareous marl in the lower parts.
		6. <i>Lower green sand</i> (marine).—Grey, yellowish, and greenish sands, ferruginous sands and sandstones, clays, cherts, and siliceous limestones
		North and South Downs, and parts of the intervening Weald of Kent, Surrey, and Sussex. Yorkshire; North of Ireland. Beauvais, France.
	H. Wealden Group.	1. <i>Weald clay</i> (freshwater).—Clay for the most part without intermixture of calcareous matter, sometimes including thin beds of sand and shelly limestone.
		2. <i>Hastings sands</i> (freshwater).—Grey, yellow, and reddish-brown sands, sandstones, clays, calcareous grits passing into limestone.
		3. <i>Purbeck beds</i> (freshwater).—Various kinds of limestones and marls.
		1, 2. Extensively developed in the central parts of Kent, Surrey, and Sussex. 3. Isle of Purbeck, in Dorsetshire.

TABLE — *continued.*

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. SECONDARY PERIOD — <i>continued.</i>	I.	
	1. <i>Portland beds</i> (marine). — Coarse shelly limestone, fine-grained white limestone, compact limestone—all more or less of an oolitic structure; beds of chert.	Isle of Portland, Tisbury in Wiltshire, Aylesbury.
	2. <i>Kimmeridge clay</i> (marine). — Blue and greyish-yellow slaty clay, containing gypsum, bituminous slate (<i>Kimmeridge coal</i>).	Near Kimmeridge, on coast of Dorsetshire; Sunning Well, near Oxford.
	3. <i>Coral rag</i> (marine). — Calcareous shelly freestones, largely oolitic; coarse limestone, full of corals; yellow sands; calcareous siliceous grits.	Headington, near Oxford; Farringdon, in Berkshire; Calne and Steeple Ashton, in Wiltshire; Somersetshire.
	4. <i>Oxford clay</i> (marine). — Dark blue tenacious clay, with septaria, bituminous shale, sandy limestone (<i>Kelloway rock</i>), iron pyrites, gypsum.	New Malton, in Yorkshire; — Lincolnshire, Cambridgeshire, Huntingdonshire, and midland counties abundantly near Oxford; Somersetshire, Dorsetshire.
	5. (a.) <i>Cornbrash</i> (marine). — Grey or bluish rubbly limestone, separated by layers of clay. (b) <i>Forest marble</i> (marine). — Calcareo-siliceous sand and gritstone; thin fissile beds of limestone, with clay partings; coarse shelly limestone.	a. Malmsbury, Atford, Wraxall, Chippenhall. b. Whichwood Forest, Oxfordshire; Frome, southeast of Bath.
	6. (a) <i>Great oolite</i> (marine). — White and yellow oolitic calcareous freestone, coarse shelly limestone, layers of clay.	a. Bath; Burford, in Oxfordshire; Bradford, in Wiltshire.

TABLE — *continued.*

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. SECONDARY PERIOD — <i>continued.</i>	I. Oolite, or Jura Limestone Group — <i>continued.</i>	
	<i>b. Stonesfield slate.</i> — Oolitic limestone, with remains of land animals, birds, amphibia, plants, sea-shells.	<i>b. Stonesfield</i> , near Woodstock, Oxfordshire.
	<i>7. Fuller's earth clay</i> (marine). — Clay, containing in some places fuller's earth.	Near Bath.
	<i>8. Inferior oolite</i> (marine). — Soft freestone, sand with calcareous concretions.	Cotteswold Hills; Dundry Hill, near Bristol.
	Limestones of various qualities, clays, sands, and sandstone, containing the same fossils as those occurring in the series of the oolitic group of England, constitute the main body of the Jura chain of mountains, and cover vast tracts of country in Germany.	
	K. Lias Group.	
	<i>Lias</i> (marine). — Shale and sandy marlstone. Blue, white, and yellow earthy limestone, usually in thin beds, interstratified with clay, often slaty and bituminous.	Lyme Regis, in Dorsetshire, and in many parts of Somersetshire, Yorkshire. In France, as at Metz, and to a considerable extent in Germany, as in the Swabian Jura.
	L. Trias, or New Red Sandstone Group.	
	1. (<i>a</i>) <i>Keuper</i> , or <i>variegated marls.</i> — Red, grey, green, blue, and white marls, sandstones, conglomerates, and shales, containing gypsum and rock-salt. (<i>b</i>) <i>Bone bed.</i> — Dark coloured limestone with remains of peculiar fishes. (<i>c</i>) Red and green marl.	<i>a.</i> Neighbourhood of Vosges Mountains, and many parts of Wurtemberg and Westphalia, Nuremberg. <i>b.</i> Axmouth, Dorset, and Aust, Somerset. <i>c.</i> Axmouth. Warwick.
	2. <i>Muschelkalk</i> (marine). — Grey, blue, and blackish limestone, with alternating clay and marl, and with siliceous layers and nodules.	Extensively developed in Germany and France. Hitherto no beds in England have been identified with the formation.

TABLE — *continued.*

III. SECONDARY PERIOD -- continued.

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in countries where it has been most studied.	Some of the Localities where the Formation occurs.
L.	3. <i>Variegated (Bunter) sandstone.</i> -- Red, white, blue, and green siliceo-argillaceous sandstone, often micaceous and containing gypsum and rock-salt.	Stuttgart. Counties of Stafford, Salop, and Worcester.
M. Magnesian Limestone Group.	1. (a) <i>Magnesian limestone</i> (marine). -- Marl-slate, shelly limestone, variegated marls, yellow magnesian limestone. (b) <i>Dolomitic conglomerate.</i> -- Fragments of subjacent rocks, with dolomitic cement. (c) <i>Zechstein of Germany.</i> -- limestone; marl-slate, containing copper ore, and impressions of fish.	a. Nottinghamshire, Derbyshire, Yorkshire, Durham, Northumberland. b. Bristol. c. Mansfeld, in Thuringia.
	2. <i>Red conglomerate.</i> -- <i>Rothliegendes</i> of the Germans. -- Red Sandstones, conglomerates, and red marls.	Neighbourhood of Exeter; Mansfeld, in Thuringia.
N. Carboniferous Group.	1. <i>Coal measures</i> (fresh-water and marine). -- Sandstones, grits, conglomerates, clays, with ironstone, shales, and limestone, interstratified with beds of coal. 2. <i>Millstone grit.</i> -- Coarse quartzose sandstone, sometimes used for millstones, usually devoid of coal. 3. <i>Mountain limestone</i> (marine). -- Grey, compact, and crystalline limestone, abounding in lead ore in North of England, and alternating with coal measures in Scotland, containing corals and shells.	Northumberland, Durham, Yorkshire, Lancashire, Staffordshire, Somersetshire, South Wales, Valleys of the Forth and Clyde. District of Liege, Westphalia, Silesia, Bohemia, &c. South Wales and Bristol coal-fields. Yorkshire. Mendip Hills, Derbyshire, Yorkshire, Durham, Northumberland, Lanarkshire, Linlithgowshire. Many parts of Ireland. North-west of Germany, Belgium, North of France.
O.	1. Yellow sandstone.	Dura Den, Fife.

TABLE — *continued.*

Periods and Groups.	Names of the principal Members and Mineral Nature of the Formation, in Countries where it has been most studied.	Some of the Localities where the Formation occurs.
III. SECONDARY PERIOD — <i>continued.</i>	O. 2. Red and green marls, red sandstone, concretionary limestone called <i>cornstone</i> , conglomerate.	Herefordshire, Forfarshire.
	3. Tilestone and grey paving-stone, red and green shale, micaceous sandstone, grey sandstone, with peculiar fishes.	Sidlaw Hills, Forfarshire ; Caithness, Cromarty.
	4. Green chloritic slates and sandstone, with shells and other fossils.	South Devon, Cornwall, Eifel.
	5. Blue crystalline limestone, with corals, shells, and other fossils of peculiar species, but with some common to the Carboniferous and Silurian groups.	Babbacombe, Torquay, and Plymouth, South Devon, Gerolstein, Eifel.
	N. B. Nos. 4. and 5. of this group (O) correspond in age to Nos. 1., 2., and 3.	
IV. PRIMARY FOSSILIFEROUS PERIOD.	P. 1. <i>Ludlow rocks</i> (marine). — Argillaceous limestone, sandy shale.	Ludlow Castle, Shropshire ; Aymestry and Woolhope, Herefordshire.
	2. <i>Wenlock limestone</i> (marine). — Coralline limestone and argillaceous shale, with nodules of earthy limestone.	Wenlock Edge, Shropshire, Dudley, Worcestershire.
	3. <i>Caradoc sandstones</i> (marine). — Shelly limestone and micaceous sandstone, quartzose grits, and sandy limestones.	Horderly, Shropshire ; and May Hill, Gloucestershire. East flank of Wrekin and Caer Caradoc, Shropshire.
	4. <i>Llandeilo flags</i> (marine). — Calcareous flags, sandstone, and schist.	Llandrindod, near Builth, Radnorshire ; Llandeilo, Caermarthenshire.
	Q. <i>Cambrian group.</i> — Stratified rocks, older than the Silurian, but in which no assemblage of organic remains specifically distinct have as yet been determined. Professor Sedgwick has proposed the name of “Cambrian” for these formations, as being of great thickness in Wales.	

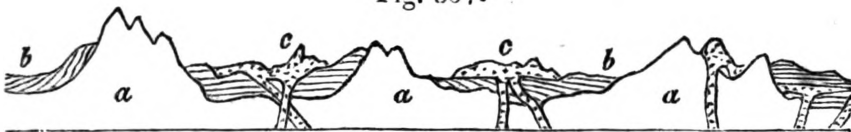
CHAPTER XXVII.

VOLCANIC ROCKS.

Trap rocks—Name, whence derived—Their igneous origin at first doubted—Their general appearance and character—Volcanic cones and craters, how formed—Mineral composition and texture of volcanic rocks—Varieties of felspar—Hornblende and augite—Isomorphism—Rocks, how to be studied—Basalt, greenstone, trachyte, porphyry, scoria, amygdaloid, lava, tuff—Alphabetical list, and explanation of names and synonyms, of volcanic rocks—Table of the analyses of minerals most abundant in the volcanic and hypogene rocks.

THE aqueous or fossiliferous rocks having now been described, we have next to examine those which may be called volcanic, in the most extended sense of that term. Suppose *a a* in the

Fig. 367.



a. Hypogene formations, stratified and unstratified.

b. Aqueous formations.

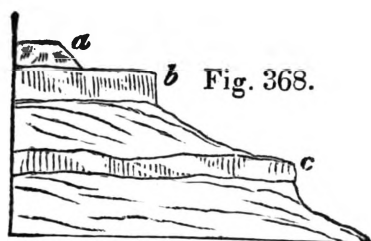
c. Volcanic rocks.

annexed diagram, to represent the crystalline formations, such as the granitic and metamorphic; *b b* the fossiliferous strata; and *c c* the volcanic rocks. These last are sometimes found, as was

explained in the first chapter and Frontispiece, breaking through *a* and *b*, sometimes overlying both, and occasionally alternating with the strata *b b*. They also are seen, in some instances, to pass insensibly into the unstratified division of *a*, or the Plutonic rocks.

When geologists first began to examine attentively the structure of the northern and western parts of Europe, they were almost entirely ignorant of the phenomena of existing volcanos. They found certain rocks, for the most part without stratification, and of a peculiar mineral composition, to which they gave different names, such as basalt, greenstone, porphyry, and amygdaloid. All these, which were recognized as belonging to one family, were called "trap" by Bergmann, from *trappa*, Swedish for a flight of steps—a name since adopted very generally into the nomenclature of the science; for it was observed that many rocks of this class occurred in great tabular masses of unequal extent, so as to form a succession of terraces or steps on the sides of hills. This configuration appears to be derived from two causes. First, the abrupt original terminations of sheets of melted matter, which have spread, whether on the land or bottom of the sea, over a level surface. For we know, in the case of lava flowing from a volcano, that a stream, when it has ceased to flow, and

grown solid, very commonly ends in a steep slope, as at *a*, Fig. 368. But, secondly, the step-like ap-



Step-like appearance of trap.

pearance arises more frequently from the mode in which horizontal masses of igneous rock, such as *b c*, intercalated between aqueous strata, have, sub-

sequently to their origin, been exposed, at different heights, by denudation. Such an outline, it is true, is not peculiar to trap rocks; great beds of limestone, and other hard kinds of stone, often presenting similar terraces and precipices: but these are usually on a smaller scale, or less numerous, than the volcanic *steps*, or form less decided features in the landscape, as being less distinct in structure and composition from the associated rocks.

Although the characters of trap rocks are greatly diversified, the beginner will easily learn to distinguish them as a class from the aqueous formations. Sometimes they present themselves, as already stated, in tabular masses, which are not divided into strata; sometimes in shapeless lumps and irregular cones, forming chains of small hills. Often they are seen in dikes or wall-like masses, intersecting fossiliferous beds. The rock is occasionally found divided into columns, often decomposing into balls of various

sizes, from a few inches to several feet in diameter. The decomposing surface very commonly assumes a coating of a rusty iron colour, from the oxidation of ferruginous matter, so abundant in the traps in which augite or hornblende occur; or, in the felspathic varieties of trap, it acquires a white opaque coating, from the bleaching of the mineral called felspar. On examining any of these volcanic rocks, where they have not suffered disintegration, we rarely fail to detect a crystalline arrangement in one or more of the component minerals. Sometimes the texture of the mass is cellular or porous, or we perceive that it has once been full of pores and cells, which have afterwards become filled with carbonate of lime, or other infiltrated mineral.

Most of the volcanic rocks produce a fertile soil by their disintegration. It seems that their component ingredients, silica, alumina, lime, potash, iron, and the rest, are in proportions well fitted for vegetation. As they do not effervesce with acids, a deficiency of calcareous matter might at first be suspected; but although *the carbonate* of lime is rare, except in the nodules of amygdaloids, yet it will be seen that lime sometimes enters largely into the composition of augite and hornblende. (See Table, p. 210.)

Cones and Craters.—In regions where the eruption of volcanic matter has taken place in

the open air, and where the surface has never since been subjected to great aqueous denudation, cones and craters constitute the most striking peculiarity of this class of formations. Many hundreds of these cones are seen in central France, in the ancient provinces of Auvergne, Velay, and Vivarais, where they observe, for the most part, a linear arrangement, and form chains of hills.

Fig. 369.



Part of the chain of extinct volcanos called the Monts Dome, Auvergne.
(Scrope.)

Although none of the eruptions have happened within the historical era, the streams of lava may still be traced distinctly descending from many of the craters, and following the lowest levels of the existing valleys. The origin of the cone and crater-shaped hill is well understood, the growth of many having been watched during volcanic eruptions. A chasm or fissure first opens in the earth, from which great volumes of steam and other gases are evolved. The explosions are so violent as to hurl up into the air fragments of broken stone, parts of which are shivered into minute atoms. At the same time melted stone or

lava usually ascends through the chimney or vent by which the gases make their escape. Although extremely heavy, this lava is forced up by the expansive power of entangled gaseous fluids, chiefly steam or aqueous vapour, exactly in the same manner as water is made to boil over the edge of a vessel when steam has been generated at the bottom by heat. Large quantities of the lava are also shot up into the air, where it separates into fragments, and acquires a spongy texture by the sudden enlargement of the included gases, and thus forms *scoriæ*, other portions being reduced to an impalpable powder or dust. The showering down of the various ejected materials round the orifice of eruption gives rise to a conical mound, in which the successive envelopes of sand and *scoriæ* form layers, dipping on all sides from a central axis. In the mean time a hollow, called a *crater*, has been kept open in the middle of the mound by the continued passage upwards of steam and other gaseous fluids. The lava sometimes flows over the edge of the crater, and thus thickens and strengthens the sides of the cone; but sometimes it breaks it down on one side, and often it flows out from a fissure at the base of the hill (see Fig. 369).*

* For a description and theory of active volcanos, see Principles of Geology.

Composition and nomenclature.—Before speaking of the connection between the products of modern volcanos and the rocks usually styled trappean, and before describing the external forms of both, and the manner and position in which they occur in the earth's crust, it will be desirable to treat of their mineral composition and names. The varieties most frequently spoken of are basalt, greenstone, syénitic greenstone, clinkstone, claystone, and trachyte; while those founded chiefly on peculiarities of texture, are porphyry, amygdaloid, lava, tuff, scoriæ, and pumice. It may be stated generally, that all these are mainly composed of two minerals, or families of simple minerals, *felspar* and *hornblende*; some almost entirely of hornblende, others of felspar.

These two minerals may be regarded as two groups, rather than species. Felspar, for example, may be, first, common felspar, that is to say, potash-felspar, in which the alkali is potash (see Table, p. 210.); or, secondly, albite, that is to say, soda-felspar, where the alkali is soda instead of potash; or, thirdly, Labrador-felspar (Labradorite), which differs not only in its iridescent hues, but also in its angle of fracture or cleavage, and its composition. We also read much of two other kinds, called glassy felspar, and compact felspar, which, however, cannot rank as varieties of equal importance, for both the albitic and

common felspar appear sometimes in transparent or *glassy* crystals ; and as to compact felspar, it is probably a compound of a less definite nature, sometimes containing, according to Dr. MacCulloch, both soda and potash.

The other group, or *hornblende*, consists principally of two varieties ; first, hornblende, and, secondly, augite, which were once regarded as very distinct, although now some eminent mineralogists are in doubt whether they are not one and the same mineral, differing only as one crystalline form of native sulphur differs from another.

The history of the changes of opinion on this point is curious and instructive. Werner first distinguished augite from hornblende ; and his proposal to separate them obtained afterwards the sanction of Haüy, Mohs, and other celebrated mineralogists. It was agreed that the form of the crystals of the two species were different, and their structure, as shown by *cleavage*, that is to say, by breaking or cleaving the mineral with a chisel, or a blow of the hammer, in the direction in which it yields most readily. It was also found by analysis that augite usually contained more lime, less alumina, and no fluoric acid ; which last, though not always found in hornblende, often enters into its composition in minute quantity. In addition to these characters, it was remarked as a geological fact, that augite and hornblende are very

rarely associated together in the same rock; and that when this happened, as in some lavas of modern date, the hornblende occurs in the mass of the rock, where crystallization may have taken place more slowly, while the augite merely lines cavities where the crystals may have been produced rapidly. It was also remarked, that in the crystalline slags of furnaces, augitic forms were frequent, the hornblendic entirely absent; hence it was conjectured that hornblende might be the result of slow, and augite of rapid cooling. This view was confirmed by the fact, that Mitscherlich and Berthier were able to make augite artificially, but could never succeed in forming hornblende. Lastly, Gustavus Rose fused a mass of hornblende in a porcelain furnace, and found that it did not, on cooling, assume its previous shape, but invariably took that of augite. The same mineralogist observed certain crystals in rocks from Siberia which presented a hornblende *cleavage*, while they had the external form of augite.

If, from these data, it is inferred that the same substance may assume the crystalline forms of hornblende or augite indifferently, according to the more or less rapid cooling of the melted mass, it is nevertheless certain that the variety commonly called augite, and recognized by a peculiar crystalline form, has usually more lime in it, and less alumina, than that called hornblende, although

the quantities of these elements do not seem to be always the same. Unquestionably the facts and experiments above mentioned show the very near affinity of hornblende and augite ; but even the convertibility of one into the other by melting and recrystallizing, does not perhaps demonstrate their absolute identity. For there is often some portion of the materials in a crystal which are not in perfect chemical combination with the rest. Carbonate of lime, for example, sometimes carries with it a considerable quantity of silice into its own form of crystal, the silice being mechanically mixed as sand, and yet not preventing the carbonate of lime from assuming the form proper to it. This is an extreme case, but in many others some one or more of the ingredients in a crystal may be excluded from perfect chemical union ; and after fusion, when the mass recrystallizes, the same elements may combine perfectly or in new proportions, and thus a new mineral may be produced. Or some one of the gaseous elements of the atmosphere, the oxygen for example, may, when the melted matter reconsolidates, combine with some one of the component elements.

The different quantity of the impurities or refuse above alluded to, which may occur in all but the most transparent and perfect crystals, may partly explain the discordant results at which experienced chemists have arrived in their analysis

of the same mineral. For the reader will find that a mineral determined to be the same by its physical characters, crystalline form, and optical properties, has often been declared by skilful analyzers to be composed of distinct elements. (See the Table at p. 210.) This disagreement seemed at first subversive of the doctrine, that there is a fixed and constant relation between the crystalline form and structure of a mineral, and its chemical composition. The apparent anomaly, however, which threatened to throw the whole science of mineralogy into confusion, was in a great degree reconciled to fixed principles by the discoveries of Professor Mitscherlich at Berlin, who ascertained that the composition of the minerals which had appeared so variable, was governed by a general law, to which he gave the name of *isomorphism* (from *ισος*, *isos*, equal, and *μορφη*, *morphe*, form.) According to this law, the ingredients of a given species of mineral are not absolutely fixed as to their kind and quality; but one ingredient may be replaced by an equivalent portion of some analogous ingredient. Thus, in augite, the lime may be in part replaced by portions of protoxide of iron, or of manganese, while the form of the crystal, and the angle of its cleavage planes, remain the same. These vicarious substitutions, however, of particular elements cannot exceed certain defined limits.

Having been led into this digression on the recent progress of mineralogy, I may here observe that the geological student must endeavour as soon as possible to familiarize himself with the characters of five at least of the most abundant simple minerals of which rocks are composed. These are, felspar, quartz, mica, hornblende, and carbonate of lime. This knowledge cannot be acquired from books, but requires personal inspection, and the aid of a teacher. It is well to accustom the eye to know the appearance of rocks under the lens. To learn to distinguish felspar from quartz is the most important step to be first aimed at. In general we may know the felspar because it can be scratched with the point of a knife, whereas the quartz, from its extreme hardness, receives no impression. But when these two minerals occur in a granular and uncrystallized state, the young geologist must not be discouraged if, after considerable practice, he often fails to distinguish them by the eye alone. If the felspar is in crystals, it is easily recognized by its cleavage: but when in grains the blow-pipe must be used, for the edges of the grains can be rounded in the flame, whereas those of *quartz* are infusible. If the geologist is desirous of distinguishing the three varieties of felspar above enumerated, or hornblende from augite, it will often be necessary to use the reflecting goniometer as a test of the

angle of cleavage, and shape of the crystal. The use of this instrument will not be found difficult.

The external characters and composition of the felspars are extremely different from those of augite or hornblende ; so that the volcanic rocks in which either of these minerals decidedly predominate, are easily recognized. But there are mixtures of the two elements in every possible proportion, the mass being sometimes exclusively composed of felspar, at other times solely of augite, or, again, of both in equal quantities. Occasionally, the two extremes, and all the intermediate gradations, may be detected in one continuous mass. Nevertheless there are certain varieties or compounds which prevail so largely in nature, and preserve so much uniformity of aspect and composition, that it is useful in geology to regard them as distinct rocks, and to assign names to them, such as basalt, greenstone, trachyte, and others, already mentioned.

Basalt.—As an example of rocks in which augite greatly prevails, basalt may first be mentioned. Although we are more familiar with this term than with that of any other kind of trap, it is difficult to define it, the name having been used so vaguely. It has been very generally applied to any trap rock of a black, bluish, or leaden-grey colour, having a uniform and compact texture. Most strictly, it consists of an intimate mixture of augite, felspar, and iron, to

which a mineral of an olive green colour, called olivine, is often superadded, in distinct grains or nodular masses. The iron is usually magnetic, and is often accompanied by another metal, titanium. Augite is the predominant mineral, the felspar being in much smaller proportions. There is no doubt that many of the fine-grained and dark-coloured trap rocks, called basalt, contain hornblende in the place of augite ; but this will be deemed of small importance after the remarks above made. Other minerals are occasionally found in basalt ; and this rock may pass insensibly into almost any variety of trap, especially into greenstone, clinkstone, and wacké, which will be presently described.

Greenstone, or *Dolerite*, is usually defined as a granular rock, the constituent parts of which are hornblende and imperfectly crystallized felspar ; the felspar being more abundant than in basalt ; and the grains or crystals of the two minerals more distinct from each other. This name may also be extended to those rocks in which augite is substituted for hornblende (the dolerite of some authors), or to those in which albite replaces common felspar, forming the rock sometimes called Andesite.

Syenitic greenstone.—The highly crystalline compounds of the same two minerals, felspar and hornblende, having a granitiform texture, and with occasionally some quartz accompany-

ing, may be called Syenitic greenstone, a rock which frequently passes into ordinary trap, and as frequently into granite.

Trachyte.—A porphyritic rock of a whitish or greyish colour, composed principally of glassy felspar, with crystals of the same, generally with some hornblende and some titaniferous iron. In composition it is extremely different from basalt, this being a felspathic, as the other is an augitic, rock. It has a peculiar rough feel, whence the name *τραχυς*, *trachus*, rough. Some varieties of trachyte contain crystals of quartz.

Porphyry is merely a certain form of rock, very characteristic of the volcanic formations. When distinct crystals of one or more minerals are scattered through an earthy or compact base, the rock is termed a porphyry (see Fig. 370.). Thus trachyte is porphyritic; for in it, as in

Fig. 370.



Porphyry.

White crystals of felspar in a dark base of hornblende and felspar.

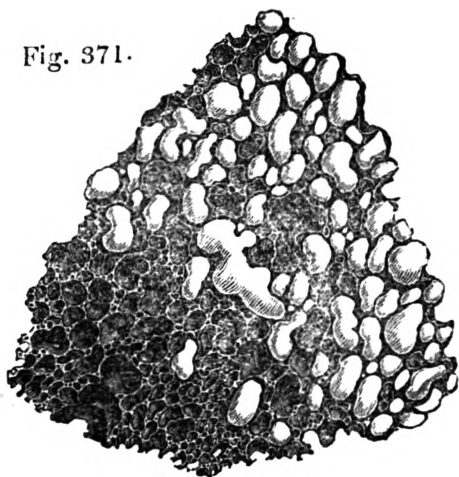
many modern lavas, there are crystals of felspar; but in some porphyries the crystals are of augite, olivine, or other minerals. If the base be greenstone, basalt, or pitchstone, the rock may be denominated greenstone-porphyry, pitch-stone-

porphyry, and so forth.

Amygdaloid. — This is also another form of igneous rock, admitting of every variety of composition. It comprehends any rock in which round or almond-shaped nodules of some mineral, such as agate, calcedony, calcareous spar, or zeolite, are scattered through a base of wacké, basalt, greenstone, or other kind of trap. It derives its name from the Greek word *amygdala*, an almond. The origin of this structure cannot be doubted, for we may trace the process of its formation in modern lavas. Small pores or cells are caused by bubbles of steam and gas confined in the melted matter. After or during consolidation, these empty spaces are gradually filled up by matter separating from the mass, or infiltrated by water permeating the rock. As these bubbles have been sometimes lengthened by the flow of the lava before it finally cooled, the contents of such cavities have the form of almonds. In some of the amygdaloidal traps of Scotland, where the nodules have decomposed, the empty cells are seen to have a glazed or vitreous coating, and in this respect exactly resemble scoriaceous lavas, or the slags of furnaces.

The annexed figure represents a fragment of stone taken from the upper part of a sheet of basaltic lava in Auvergne. One half is scoriaceous, the pores being perfectly empty, the other part is amygdaloidal, the pores or cells being mostly filled up with carbonate of lime, forming white kernels.

Fig. 371.



Scoriaceous lava in part converted into an amygdaloid.
Montagne de la Veille, Department of Puy de Dome, France.

Scoriæ and *Pumice* may next be mentioned as porous rocks, produced by the action of gases on materials melted by volcanic heat. *Scoriæ* are usually of a reddish brown and black colour, and are the cinders and slags of basaltic or augitic lavas. *Pumice* is a light, spongy, fibrous substance, produced by the action of gases on trachytic and other lavas; the relation, however, of its origin to the composition of lava is not yet well understood. Von Buch says that it never occurs where only Labrador-felspar is present.

Lava.—This term has a somewhat vague signification, having been applied to all melted matter observed to flow in streams from volcanic vents. When this matter consolidates in the open air, the upper part is usually scoriaceous, and the mass becomes more and more stony as we descend, or in proportion as it has consolidated more

slowly and under greater pressure. At the bottom, however, of a stream of lava, a small portion of scoriaceous rock very frequently occurs, formed by the first thin sheet of liquid matter, which often precedes the main current, or in consequence of the contact with water in or upon the damp soil.

The more compact lavas are often porphyritic, but even the scoriaceous part sometimes contains imperfect crystals, which have been derived from some older rocks, in which the crystals pre-existed, but were not melted, as being more infusible in their nature.

Although melted matter rising in a crater, and even that which enters rents on the side of a crater, is called lava, yet this term belongs more properly to that which has flowed either in the open air or on the bed of a lake or sea. If the same fluid has not reached the surface, but has been merely injected into fissures below ground, it is called trap.

There is every variety of composition in lavas ; some are trachytic, as in the Peak of Teneriffe ; a great number are basaltic, as in Vesuvius and Auvergne ; others are Andesitic, as those of Chili ; some of the most modern in Vesuvius consist of green augite, and many of those of Etna of augite and Labrador-felspar.*

Trap tuff, volcanic tuff.—Small angular frag-

* G. Rose, Ann. des Mines, tom. 8. p. 32.

ments of the scorix and pumice, above mentioned, and the dust of the same, produced by volcanic explosions, form the tuffs which abound in all regions of active volcanos, where showers of these materials, together with small pieces of other rocks ejected from the crater, fall down upon the land or into the sea. Here they often become mingled with shells, and are stratified. Such tuffs are sometimes bound together by a calcareous cement, and form a stone susceptible of a beautiful polish. But even when little or no lime is present, there is a great tendency in the materials of ordinary tuffs to cohere together.

Besides the peculiarity of their composition, some tuffs, or *volcanic grits*, as they have been termed, differ from ordinary sandstones by the angularity of their grains. When the fragments are coarse, the rock is styled a volcanic *breccia*. *Tufaceous conglomerates* result from the intermixture of rolled fragments or pebbles of volcanic and other rocks with tuff.

According to Mr. Scrope, the Italian geologists confine the term *tuff*, or *tufa*, to felspathose mixtures, and those composed principally of pumice, using the term *peperino* for the basaltic tuffs.*

We meet occasionally with extremely compact beds of volcanic materials, interstratified with fossiliferous rocks. These may sometimes be

* Geol. Trans., vol. ii. p. 211. Second Series.

tuffs, although their density or compactness is such as to cause them to resemble many of those kinds of trap which are found in ordinary dikes. The chocolate-coloured mud, which was poured for weeks out of the crater of Graham's Island, in the Mediterranean, in 1831, must, when unmixed with other materials, have constituted a stone heavier than granite. Each cubic inch of the impalpable powder which has fallen for days through the atmosphere during some modern eruptions, has been found to weigh, without being compressed, as much as ordinary trap rocks, and to be often identical with these in mineral composition.

The fusibility of the igneous rocks generally exceeds that of other rocks, for there is much alkaline matter and lime in their composition, which serves as a flux to the large quantity of silica, which would be otherwise so refractory an ingredient.

It is remarkable that, notwithstanding the abundance of this silica, quartz is usually wanting in the volcanic rocks, or is present only as an occasional mineral, like mica. The elements of mica, as of quartz, occur in lava and trap, but the circumstances under which these rocks are formed are evidently unfavourable to the development of mica and quartz, minerals so characteristic of the hypogene formations.

It would be tedious to enumerate all the varieties of trap and lava which have been regarded by different observers as sufficiently abundant to deserve distinct names, especially as each investigator is too apt to exaggerate the importance of local varieties which happen to prevail in districts best known to him. It will be useful, however, to subjoin here, in the form of a glossary, an alphabetical list of the names and synonyms most commonly in use, with brief explanations, to which I have added a table of the analysis of the simple minerals most abundant in the volcanic and hypogene rocks.

Explanation of the names, synonyms, and mineral composition of the more abundant volcanic rocks.

AMPHIBOLITE. See Hornblende rock, amphibole being Haüy's name for hornblende.

AMYGDALOID. A particular form of volcanic rock ; see p. 200.

AUGITE ROCK. A kind of basalt or greenstone, composed wholly or principally of granular augite (*Leonhard's Mineralreichs*, 2d edition, p. 85.)

AUGITIC-PORPHYRY. Crystals of Labrador-felspar and of augite, in a green or dark grey base. (*Rose, Ann. des Mines*, tom. 8. p. 22. 1835.)

BASALT. Chiefly augite — an intimate mixture of augite and felspar with magnetic iron, olivine, &c. See p. 197. The yellowish green mineral called olivine, can easily be

distinguished from yellowish felspar by its infusibility, and having no cleavage. The edges turn brown in the flame of the blow-pipe.

CLAYSTONE and CLAYSTONE-PORPHYRY. An earthy and compact stone, usually of a purplish colour, like an indurated clay; passes into hornstone; generally contains scattered crystals of felspar and sometimes of quartz.

CLINKSTONE. *Syn.* Phonolite, fissile Petrosilex; a greenish or greyish rock, having a tendency to divide into slabs and columns; hard, with clean fracture, ringing under the hammer; principally composed of compact felspar, and, according to Gmelin, of felspar and mesotype. (*Leonhard, Mineralreichs*, p. 102) A rock much resembling clinkstone, and called by some Petrosilex, contains a considerable percentage of quartz and felspar. As both trachyte and basalt pass into clinkstone, the rock so called must be very various in composition.

COMPACT FELSPAR, which has also been called Petrosilex; the rock so called includes the hornstone of some mineralogists, is allied to clinkstone, but is harder, more compact, and translucent. It is a varying rock, of which the chemical composition is not well defined, and is perhaps the same as that of clay. (*MacCulloch's Classification of Rocks*, p. 481.) Dr. MacCulloch says, that it contains both potash and soda.

CORNEAN. A variety of claystone allied to hornstone. A fine homogeneous paste, supposed to consist of an aggregate of felspar, quartz, and hornblende, with occasionally epidote, and perhaps chlorite; it passes into compact felspar and hornstone. (*De la Beche, Geol. Trans.*, second series, vol. 2. p. 3.)

DIALLAGE ROCK. *Syn.* Euphotide, Gabbro, and some Ophiolites. Compounded of felspar and diallage, sometimes with the addition of serpentine, or mica, or quartz. (*MacCulloch, ibid.* p. 648.)

DIORITE. A kind of greenstone, which see. Components,

felspar and hornblende in grains. According to *Rose, Ann. des Mines*, tom. 8. p. 4., *diorite* consists of albite and hornblende.

DIORITIC-PORPHYRY. A porphyritic greenstone, composed of crystals of albite and hornblende, in a greenish or blackish base. (*Rose, ibid.* p. 10.)

DOLERITE. Formerly defined as a synonym of greenstone, which see. But according to *Rose (ibid.* p. 32.), its composition is black augite and Labrador-felspar; according to *Leonhard (Mineralreichs, &c.* p. 77.), augite, Labrador-felspar, and magnetic iron.

DOMITE. An earthy condition of *trachyte*, found in the Puy de Dome, in Auvergne.

EUPHOTIDE. A mixture of grains of Labrador-felspar and diallage. (*Rose, ibid.* p. 19.) According to some, this rock is defined to be a mixture of augite or hornblende, and Saussurite, a mineral allied to jade. (*Allan's Mineralogy*, p. 158.) See Diallage rock.

FELSPAR-PORPHYRY. *Syn.* Hornstone-porphyry; a base of felspar, with crystals of felspar, and crystals and grains of quartz. See also Hornstone.

GABBRO, *see* Diallage-rock.

GREENSTONE. *Syn.* Dolerite and diorite; components, hornblende and felspar, or augite and felspar in grains. See above, p. 198.

GREYSTONE. (Graustein of Werner.) Lead grey and greenish rock, composed of felspar and augite, the felspar being more than seventy-five per cent. (*Scrope, Journ. of Sci.*, No. 42. p. 221.) Greystone lavas are intermediate in composition between basaltic and trachytic lavas.

HORNBLLENDE ROCK. A greenstone, composed principally of granular hornblende, or augite. (*Leonhard, Mineralreichs, &c.*, p. 85.)

HORNSTONE, HORNSTONE-PORPHYRY. A kind of felspar porphyry (*Leonhard, ibid.*), with a base of hornstone, a min-

eral approaching near to flint, differing from compact felspar in being infusible.

HYPERSTHENE ROCK, a mixture of grains of Labrador-felspar and hypersthene (*Rose, Ann. des Mines*, tom. 8. p. 13.), having the structure of syenite or granite; abundant among the traps of Sky. In a geological view, it has been called a greenstone, in which hypersthene takes the place of hornblende.

MELAPHYRE. A variety of black porphyry, the base being black augite with crystals of felspar; from *μελας*, *melas*, black.

OBSIDIAN. Vitreous lava like melted glass, nearly allied to pitchstone.

OPHIOLITE, sometimes same as Diallage rock (*Leonhard*, p. 77.); sometimes a kind of serpentine.

OPHITE. A green porphyritic rock, composed chiefly of hornblende, with crystals of that mineral in a base of the same, mixed with some felspar. It passes into serpentine by a mixture of talc. (*Burat's D'Aubuisson*, tom. 2. p. 63.)

PEARLSTONE. A volcanic rock having the lustre of mother of pearl; usually having a nodular structure; intimately related to obsidian, but less glassy.

PEPERINO. A form of volcanic tuff, composed of basaltic scoræ. See p. 203.

PETROSILEX. See Clinkstone and Compact Felspar.

PHONOLITE. *Syn.* of Clinkstone, which see.

PITCHSTONE; vitreous lava, less glassy than obsidian; a blackish green rock resembling glass, having a resinous lustre and appearance of pitch; composition various, usually felspar and augite; passes into basalt; occurs in veins, and in Arran forms a dike thirty feet wide, cutting through sandstone; forms the outer walls of some basaltic dikes.

PORPHYRY. Any rock in which detached crystals of felspar, or of one or more minerals, are diffused through a base. See p. 199.

POZZOLANA. A kind of tuff. *See* Vol. I. p. 78.

PUMICE. A light, spongy, fibrous form of trachyte. *See* p. 201.

PYROXENIC-PORPHYRY, same as augitic-porphry, pyroxene being Haüy's name for augite.

SCORIÆ. *Syn.* volcanic cinders; reddish brown or black porous form of lava. *See* p. 201.

SERPENTINE. A greenish rock, in which there is much magnesia; usually contains diallage, which is nearly allied to the simple mineral called serpentine. Occurs sometimes, though rarely, in dikes, altering the contiguous strata; is indifferently a member of the trappean or hypogene series.

SYENITIC-GREENSTONE; composition, crystals or grains of felspar and hornblende. *See* p. 198.

TEPHRINE, synonymous with lava.

TOADSTONE. A local name in Derbyshire for a kind of wacké, which *see*.

TRACHYTE, chiefly composed of glassy felspar, with crystals of glassy felspar. *See* p. 199.

TRAP TUFF. *See* p. 203.

TRASS. A kind of tuff or mud poured out by lake-craters during eruptions; common in the Eifel, in Germany.

TUFACEOUS CONGLOMERATE. *See* p. 203.

TUFF. *Syn.* Trap-tuff, volcanic tuff. *See* p. 203.

VITREOUS LAVA. *See* Pitchstone and Obsidian.

VOLCANIC TUFF. *See* p. 203.

WACKÉ. A soft and earthy variety of trap, having an argillaceous aspect. It resembles indurated clay, and when scratched, exhibits a shining streak.

WHINSTONE. A Scotch provincial term for greenstone and other hard trap rocks.

ANALYSIS OF MINERALS MOST ABUNDANT IN THE VOLCANIC AND
HYPOGENE ROCKS.

	Silica.	Alumina.	Magnesia.	Lime.	Potash.	Soda.	Iron Oxide.	Manganese.	Remainder.
Actinolite (Bergman)	-	-	22.	-	-	-	3.	-	-
Albite (Rose)	64.	20.53	-	a trace	-	9.12	a trace	a trace	-
— (mean of 4 analyses)	68.84	19.44	0.13	0.22	-	9.95	17.38	0.09	-
Augite (Rose)	-	-	4.99	22.19	-	-	10.75	0.67	-
— (mean of 4 analyses)	53.36	1.	11.26	20.9	-	-	-	-	43.05 C.
Carbonate of Lime (Biot)	-	-	-	56.33	-	-	2.7	-	0.27 W.
Chiasolite (Landgrabe)	-	30.17	4.12	-	-	-	43.	-	-
Chlorite (Vauquelin)	26.	18.5	8.	-	-	2.	30.63	-	6.92 W.
— (mean of 3 analyses)	27.43	17.9	14.56	0.50	1.56	-	10.5	-	-
Diallage (Klaproth)	-	-	27.5	-	-	-	11.53	-	8.54 W.
— (mean of 3 analyses)	60.	-	26.41	5.58	-	-	24.	1.5	-
Epidote (Vauquelin)	37.	21.	-	15.	-	-	1.	-	-
Felspar, common, (Vauq.)	-	17.02	-	3.	13.	-	0.75	-	-
— (Rose)	-	17.5	-	1.25	12.	-	0.74	-	-
— (mean of 7 analyses)	64.04	18.94	-	0.76	13.66	-	36.	0.25	-
Garnet (Klaproth)	-	27.25	-	-	-	-	16.	-	-
— (Phillips)	43.	16.	-	20.	-	-	-	-	-

	Silica.	Alumina.	Magnesia.	Lime.	Potash.	Soda.	Iron Oxide.	Manganese.	Remainder.
Hornblende (Klap.)	42.	12.	2.25	11.	a trace	-	30.	0.25	
— (Bonsdorff)	45.69	12.18	18.79	13.85	-	-	7.32	0.22	1.5 F.
Hypersthene (Klaproth)	54.25	2.25	14.	1.5	-	-	24.5	a trace	1. W.
Labrador-felspar (Klap.)	55.75	26.5	-	11.	-	4.	1.25	-	0.5 W.
Leucite (Klap.)	53.75	24.62	-	-	21.35	-	-	-	
Mesotype (Gehlen)	54.46	19.70	-	1.61	-	15.09	-	-	9.83 W.
Mica (Klaproth)	42.5	11.5	9.	-	10.	-	22.	2.	
— (Vauquelin)	50.	35.	-	1.33	-	-	7.	-	
— (mean of 3 analyses)	45.83	22.58	-	-	11.08	-	14.	1.45	
Olivine (Klaproth)	50.	-	38.5	-	-	-	12.	-	
Schörl or Tourmaline (Gmelin)	35.48	34.75	4.68	-	0.48	1.75	17.44	1.89	4.02 B.
— (mean of 6 analyses)	36.03	35.82	4.44	0.28	0.71	1.96	13.71	1.62	
Serpentine (Hisinger)	43.07	0.25	40.37	0.5	-	-	1.17	-	2.45 W.
— (mean of 5 analyses)	37.29	4.97	36.8	2.89	-	-	3.14	-	12.77 W.
Steatite (Vauquelin)	64.	-	22.	-	-	-	3.	-	5. W.
— (mean of 3 anal. by Klap.)	48.3	6.18	26.65	-	-	-	2.	-	9.5 W.
Talc (Klaproth)	61.75	-	30.5	-	2.75	-	2.5	-	

In the last column of the above Table, the letters B. C. F. W. represent Boracic acid, Carbonic acid, Fluoric acid, and Water.

CHAPTER XXVIII.

VOLCANIC ROCKS — *continued.*

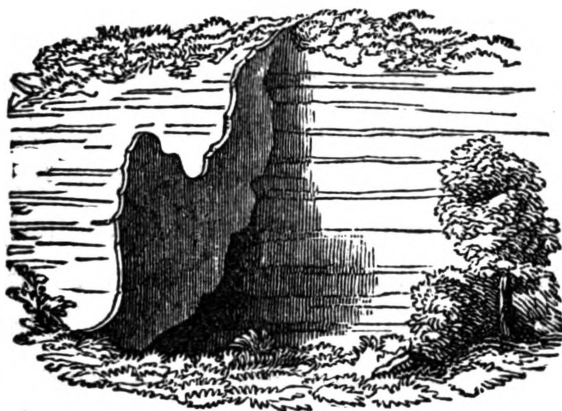
Trap dikes — sometimes project — sometimes leave fissures vacant by decomposition—Branches and veins of trap—Dikes more crystalline in the centre—Foreign fragments of rock imbedded—Strata altered at or near the contact—Obliteration of organic remains—Conversion of chalk into marble—and of coal into coke—Inequality in the modifying influence of dikes—Trap interposed between strata—Columnar and globular structure—Relation of trappean rocks to the products of active volcanos—Submarine lava and ejected matter corresponds generally to ancient trap.

HAVING in the last chapter spoken of the composition and mineral characters of volcanic rocks, I shall next describe the manner and position in which they occur in the earth's crust, and their external forms. Now the leading varieties, such as basalt, greenstone, trachyte, porphyry, and the rest are found sometimes in dikes penetrating stratified and unstratified formations, sometimes in shapeless masses protruding through or overlying them, or in horizontal sheets intercalated between strata.

Volcanic dikes.—Fissures have already been spoken of as occurring in all kinds of rocks, some a few feet, others many yards in width, and often

filled up with earth or angular pieces of stone, or with sand and pebbles. Instead of such materials, suppose a quantity of melted stone to be driven or injected into an open rent, and there consolidated, we have then a tabular mass resembling a wall, and called a trap dike. It is not uncommon to find such dikes passing through strata of soft materials, such as tuff or shale, which, being more perishable than the trap, are often washed away by the sea, rivers, or rain, in which case the dike stands prominently out in the face of precipices, or on the level surface of a country. (See the annexed figure.)*

Fig. 372.

*Dike in inland valley, near the Brazen Head, Madeira.*

In the islands of Arran, Sky, and other parts of Scotland, where sandstone, conglomerate, and other hard rocks are traversed by dikes of trap, the converse of the above phenomenon is seen.

* I have been favoured with this drawing by Captain B. Hall.

The dike having decomposed more rapidly than the containing rock, has once more left open the original fissure, often for a distance of many yards

Fig. 373.



Fissure left vacant by decomposed trap.
Strathaird, Sky. (MacCulloch.)

inland from the seacoast, as represented in the annexed view (Fig. 273.). In these instances the greenstone of the dike is usually more tough and hard than the sandstone; but chemical action, and chiefly the oxidation of the iron, has given rise to the more rapid decay.

There is yet another case, by no means uncommon in Arran and other parts of Scotland, where the strata in contact with the dike, and for a certain distance from it, have been hardened, so as to resist the action of the weather more than the dike itself, or the surrounding rocks. When this happens, two parallel walls of indurated strata are seen protruding above the general level of the country, and following the course of the dike.

As fissures sometimes send off branches, or divide into two or more fissures of equal size, so also we find trap dikes bifurcating and ramifying, and sometimes they are so tortuous as to be called

veins, though this is more common in granite than in trap. The accompanying sketch (Fig. 374.) by

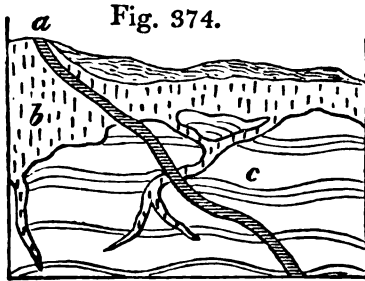


Fig. 374.

Dr. MacCulloch represents part of a sea-cliff in Argyleshire, where an overlying mass of trap, *b*, sends out some veins which terminate downwards. Another trap

vein, *a a*, cuts through both the limestone, *c*, and the trap, *b*.

In Fig. 375. a ground plan is given of a ramifying dike of greenstone, which I observed cutting through sandstone on the beach near Kildonan Castle, in Arran. The larger branch varies from five to seven feet in width, which will afford a scale of measurement for the whole.

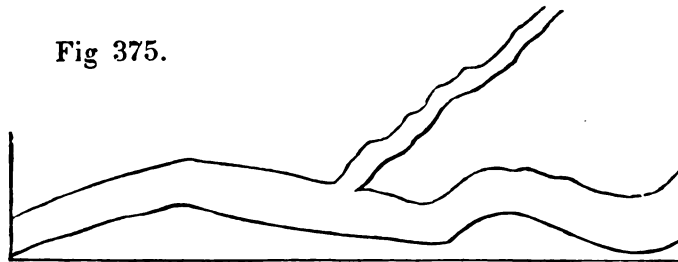


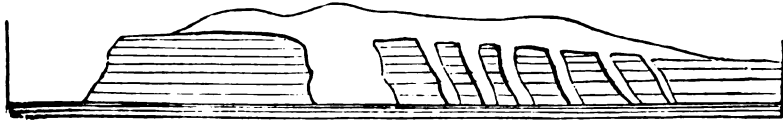
Fig 375.

Ground plan of greenstone dike traversing sandstone. Arran.

In the Hebrides and other countries, the same masses of trap which occupy the surface of the country far and wide, concealing the subjacent stratified rocks, are seen also in the sea-cliffs, prolonged downwards in veins or dikes, which probably unite with other masses of igneous rock at

a greater depth. The largest of the dikes represented in the annexed diagram, and which are seen in part of the coast of Sky, is no less than 100 feet in width.

Fig. 376.



Trap dividing and covering sandstone near Suishnish in Sky. (MacCulloch.)

Every variety of trap rock is sometimes found in these dikes, as basalt, greenstone, felspar-porphry, and more rarely trachyte. The amygdaloidal traps also occur, and even tuff and breccia, for the materials of these last may be washed down into open fissures at the bottom of the sea, or during eruptions on the land may be showered into them from the air.

Some dikes of trap may be followed for leagues uninterruptedly in nearly a straight direction, as in the north of England, showing that the fissures which they fill must have been of extraordinary length.

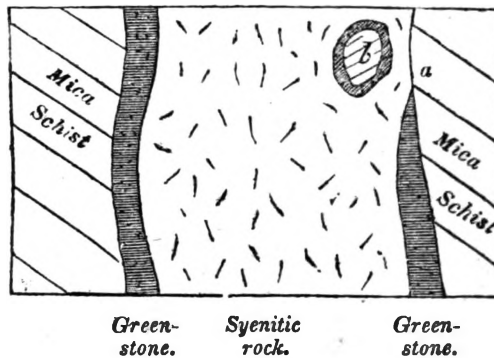
Dikes more crystalline in the centre.—In many cases trap at the edges or sides of a dike is less crystalline or more earthy than in the centre, in consequence of the melted matter having cooled more rapidly by coming in contact with the cold sides of the fissure ; whereas, in the centre, the

matter of the dike being kept long in a fluid or soft state, the crystals are slowly formed. In the ancient part of Vesuvius a thin band of half-vitreous lava is found at the edge of some dikes. At the junction of greenstone dikes with limestone, a *sahlband*, or selvage, of serpentine is occasionally observed.

On the left shore of the fiord of Christiania, in Norway, a remarkable dike of syenitic greenstone is traced through transition strata, until at length, in the promontory of Næsodden, it enters mica-schist. Fig. 377. represents a ground plan, where

Fig. 377.

Syenitic greenstone dike of Næsodden, Christiania.

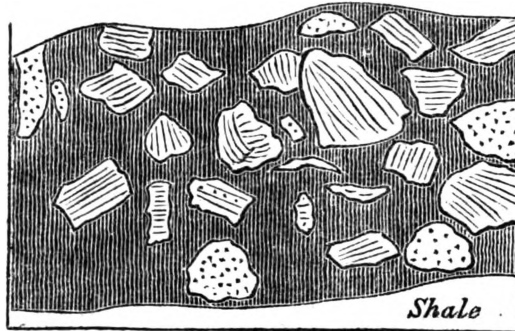


the dike appears eight paces in width. In the middle it is highly crystalline and granitiform, of a purplish colour, and containing a few crystals of mica, and strongly contrasted with the whitish mica-schist, between which and the syenitic rock there is usually on each side a distinct black band, 18 inches wide, of dark greenstone. When first

seen these bands have the appearance of two accompanying dikes; yet they are, in fact, only the different form which the syenitic materials have assumed where near to or in contact with the mica-schist. At one point, *a*, one of the sahl-bands terminates for a space; but near this there is a large detached block, *b*, having a gneiss-like structure, consisting of hornblende and felspar, which is included in the midst of the dike. Round this a smaller encircling zone is seen, of dark basalt, or fine-grained greenstone, nearly corresponding to the larger ones which border the dike, but only one inch wide.*

The fact above alluded to, of a foreign fragment, such as *b* (Fig.377.), included in the midst

Fig. 378.



Greenstone dike, with fragments of gneiss; Sorgenfri, Christiania.

of the trap, as if torn off from some subjacent rock or the walls of a fissure, is by no means uncommon. A fine illustration is seen in a dike

* This dike has been described by Professor Keilhau, of Christiania, in whose company I examined it.

of greenstone, ten feet wide, in the northern suburbs of Christiania, in Norway, of which the annexed figure is a ground plan. The dike passes through shale, known by its fossils to belong to the transition or Silurian series. In the black base of greenstone are angular and roundish pieces of gneiss, some white, others of a light flesh-colour, some without lamination, like granite, others with laminæ, which, by their various and often opposite directions, show that they have been scattered at random through the matrix. These imbedded pieces of gneiss measure from one to about eight inches in diameter.

Rocks altered by volcanic dikes. —After these remarks on the form and composition of dikes themselves, I shall describe the alterations which they sometimes produce in the rocks in contact with them. The changes are usually such as the intense heat of melted matter and the entangled gases might be expected to cause.

Plas-Newydd. — A striking example, near Plas-Newydd, in Anglesea, has been described by Professor Henslow.* The dike is 134 feet wide, and consists of a rock which is a compound of felspar and augite (dolerite of some authors). Strata of shale and argillaceous limestone, through which it cuts perpendicularly, are altered to a

* Cambridge Transactions, vol. i. p. 402.

distance of thirty, or even, in some places, to thirty-five feet from the edge of the dike. The shale, as it approaches the trap, becomes gradually more compact, and is most indurated where nearest the junction. Here it loses part of its schistose structure, but the separation into parallel layers is still discernible. In several places the shale is converted into hard porcellanous jasper. In the most hardened part of the mass the fossil shells, principally *Productæ*, are nearly obliterated; yet even here their impressions may frequently be traced. The argillaceous limestone undergoes analogous mutations, losing its earthy texture as it approaches the dike, and becoming granular and crystalline. But the most extraordinary phenomenon is the appearance in the shale of numerous crystals of analcime and garnet, which are distinctly confined to those portions of the rock affected by the dike.* Garnets have been observed, under very analogous circumstances, in High Teesdale, by Professor Sedgwick, where they occur in shale and limestone, altered by basalt.†

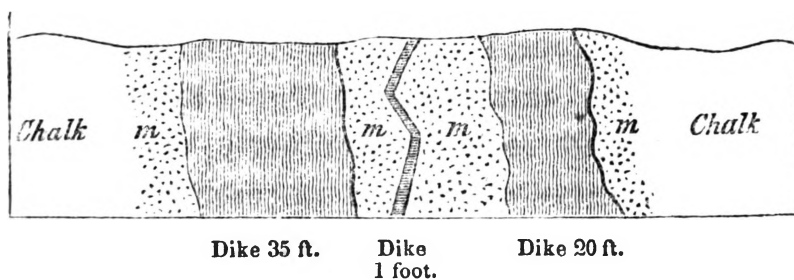
Antrim. — In several parts of the county of Antrim, in the north of Ireland, chalk with flints is traversed by basaltic dikes. The chalk is there

* Cambridge Transactions, vol. i. p. 410.

† Ibid. vol. ii. p. 175.

converted into granular marble near the basalt, the change sometimes extending eight or ten feet from the wall of the dike, being greatest near the point of contact, and thence gradually decreasing till it becomes evanescent. "The extreme effect," says Dr. Berger, "presents a dark brown crystalline limestone, the crystals running in flakes as large as those of coarse primitive (*metamorphic*) limestone; the next state is saccharine, then fine grained and arenaceous; a compact variety, having a porcellanous aspect and a bluish-grey colour, succeeds: this, towards the outer edge, becomes yellowish-white, and insensibly graduates into the unaltered chalk. The flints in the altered chalk usually assume a grey yellowish colour."* All traces of organic remains are effaced in that part of the limestone which is most crystalline.

Fig. 379.



Basaltic dikes in chalk in island of Rathlin, Antrim.
Ground plan, as seen on the beach. (Conybeare and Buckland.)†

* Dr. Berger, Geol. Trans., First Series, vol. iii. p. 172.

† Geol. Trans., First Series, vol. iii. p. 210. and plate 10.

The annexed drawing (Fig. 379.) represents three basaltic dikes traversing the chalk, all within the distance of ninety feet. The chalk contiguous to the two outer dikes is converted into a finely granular marble, *m m*, as are the whole of the masses between the outer dikes and the central one. The entire contrast in the composition and colour of the intrusive and invaded rocks, in these cases, renders the phenomena peculiarly clear and interesting.

Another of the dikes of the north-east of Ireland has converted a mass of red sandstone into hornstone.* By another, the slate clay of the coal measures has been indurated, and has assumed the character of flinty slate†; and in another place the slate clay of the lias has been changed into flinty slate, which still retains numerous impressions of ammonites.‡

It might have been anticipated that beds of coal would, from their combustible nature, be affected in an extraordinary degree by the contact of melted rock. Accordingly, one of the greenstone dikes of Antrim, on passing through a bed of coal, reduces it to a cinder for the space of nine feet on each side.§

* Geol. Trans., First Series, vol. iii. p. 201.

† Ibid. p. 205.

‡ Ibid. p. 213.; and Playfair, *Illust. of Hutt. Theory*. s. 253.

§ Geol. Trans., First Series, vol. iii. p. 206.

At Cockfield Fell, in the north of England, a similar change is observed. Specimens taken at the distance of about thirty yards from the trap are not distinguishable from ordinary pit coal ; those nearer the dike are like cinders, and have all the character of coke ; while those close to it are converted into a substance resembling soot.*

As examples might be multiplied without end, I shall merely select one or two others, and then conclude. The rock of Stirling Castle is a calcareous sandstone, fractured and forcibly displaced by a mass of greenstone which has evidently invaded the strata in a melted state. The sandstone has been indurated, and has assumed a texture approaching to hornstone near the junction. In Arthur's Seat and Salisbury Craig, near Edinburgh, a sandstone which comes in contact with greenstone is converted into a jaspideous rock.†

The secondary sandstones in Sky are converted into solid quartz in several places, where they come in contact with veins or masses of trap ; and a bed of quartz, says Dr. MacCulloch, found near a mass of trap, among the coal strata of Fife, was in all probability a stratum of ordi-

* Sedgwick, Camb. Trans., vol. ii. p. 37.

† Illust. of Hutt. Theory, § 253. and 261. Dr. MacCulloch, Geol. Trans., First Series, vol. ii. p. 305.

nary sandstone, having been subsequently indurated and turned into quartzite by the action of heat.*

But although strata in the neighbourhood of dikes are thus altered in a variety of cases, shale being turned into flinty slate or jasper, limestone into crystalline marble, sandstone into quartz, coal into coke, and the fossil remains of all such strata wholly or in part obliterated, it is by no means uncommon to meet with the same rocks, even in the same districts, absolutely unchanged in the proximity of volcanic dikes.

This great inequality in the effects of the igneous rocks may often arise from an original difference in their temperature, and in that of the entangled gases, such as is ascertained to prevail in different lavas, or in the same lava near its source and at a distance from it. The power also of the invaded rocks to conduct heat may vary, according to their composition, structure, and the fractures which they may have experienced, and perhaps, also, according to the quantity of water (so capable of being heated) which they contain. It must happen in some cases that the component materials are mixed in such proportions as prepare them readily to enter into chemical union, and form new minerals; while in other cases the mass may be more homo-

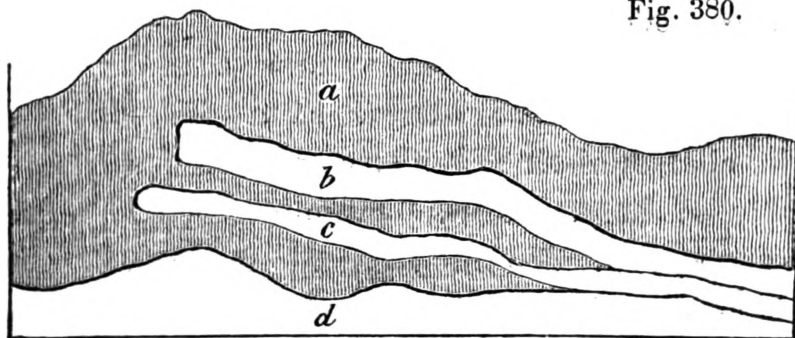
* *Syst. of Geol.*, vol. i. p. 206.

geneous, or the proportions less adapted for such union.

We must also take into consideration, that one fissure may be simply filled with lava, which may begin to cool from the first ; whereas in other cases the fissure may give passage to a current of melted matter, which may ascend for days or months, feeding streams which are overflowing the country above, or are ejected in the shape of scoriæ from some crater. If the walls of a rent, moreover, are heated by hot vapour before the lava rises, as we know may happen on the flanks of a volcano, the additional caloric supplied by the dike and its gases will act more powerfully.

Intrusion of trap between strata.—In proof of the mechanical force which the fluid trap has sometimes exerted on the rocks into which it has

Fig. 380.



*Trap interposed between displaced beds of limestone and shale, at White Force, High Teesdale, Durham. (Sedgwick.)**

intruded itself, I may refer to the Whin-Sill, where a mass of basalt, from sixty to eighty feet

* Camb. Trans., vol. ii. p. 180.

in height, represented by *a*, Fig. 380., is in part wedged in between the rocks of limestone, *b*, and shale, *c*, which have been separated from the great mass of limestone and shale, *d*, with which they were united.

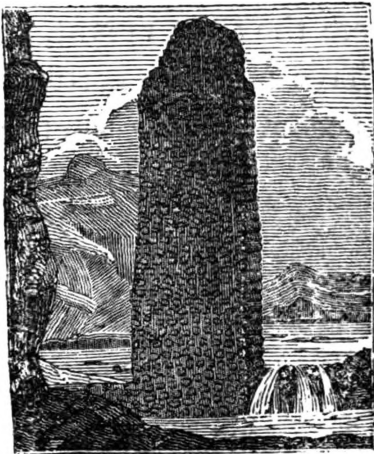
The shale in this place is indurated ; and the limestone, which at a distance from the trap is blue, and contains fossil corals, is here converted into granular marble without fossils.

Masses of trap are not frequently met with intercalated between strata, and maintaining their parallelism to the planes of stratification throughout large areas. They must in some places have forced their way laterally between the divisions of the strata, a direction in which there would be the least resistance to an advancing fluid, if no vertical rents communicated with the surface, and a powerful hydrostatic pressure was caused by gases propelling the lava upwards.

Columnar and globular structure.—One of the characteristic forms of volcanic rocks, especially of basalt, is the columnar, where large masses are divided into regular prisms, sometimes easily separable, but in other cases adhering firmly together. The columns vary in the number of angles, from three to twelve ; but they have most commonly from five to seven sides. . They are often divided transversely, at nearly equal distances, like the joints in a vertebral column,

as in the Giants' Causeway, in Ireland. They vary exceedingly in respect to length and diameter. Dr. MacCulloch mentions some in Sky which are about 400 feet long; others, in Morven, not exceeding an inch. In regard to diameter, those of Ailsa measure nine feet, and those of Morven an inch or less.* They are usually straight, but sometimes curved; and examples of both these occur in the island of Staffa. In a horizontal bed or sheet of trap the columns are vertical; in a vertical dike they are horizontal. Among other examples of the last mentioned phenomenon is the mass of basalt, called the Chimney, in St. Helena (see Fig. 381.), a pile of hexagonal prisms, 64 feet high, evidently the

Fig. 381.



Volcanic dike composed of horizontal prisms. St. Helena.

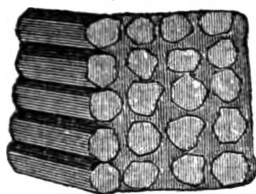
remainder of a narrow dike, the walls of rock which the dike originally traversed having been removed down to the level of the sea. In Fig. 382. a small portion of this dike is represented on a less reduced scale.†

It being assumed that columnar trap has con-

* MacCulloch, *Syst. of Geol.*, vol. ii. p. 137.

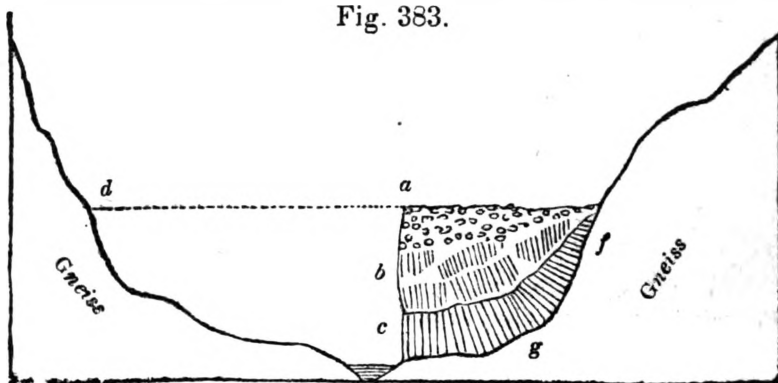
† Seale's *Geognosy of St. Helena*, plate 9.

Fig. 382.

Small portion of the dike
in Fig. 381.

solidated from a fluid state, the prisms are said to be always at right angles to the *cooling surfaces*. If these surfaces, therefore, instead of being either perpendicular, or horizontal, are curved, the columns ought to be inclined at every angle to the horizon; and there is a beautiful exemplification of this phenomenon in one of the valleys of the Vivarais, a mountainous district in the South of France, where, in the midst of a region of gneiss, a geologist encounters unexpectedly several volcanic cones of loose sand and scorïæ. From the crater of one of these cones, called La Coupe d'Ayzac, a stream of lava descends and occupies the bottom of a narrow valley, except at those points where the river Volant, or the torrents which join it, have cut away portions of the solid lava. The accompanying sketch

Fig. 383.

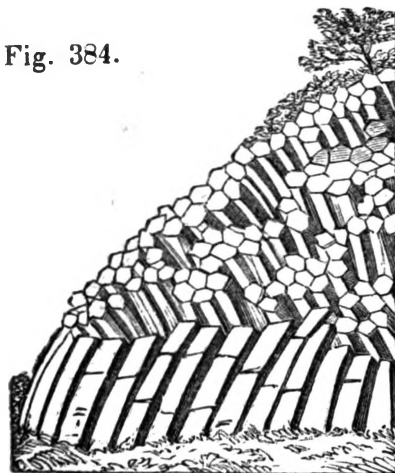


Lava of La Coupe d'Ayzac, near Antraigue, in the Province of Ardeche.

(Fig. 383.) represents the remnant of the lava, at one of the points where a lateral torrent joins the

main valley of the Volant. It is clear that the lava once filled the whole valley up to the dotted line *da*; but the river has gradually swept away all below that line, while the tributary torrent has laid open a transverse section; by which we perceive, in the first place, that the lava is composed, as usual in this country, of three parts: the uppermost, at *a*, being scoriaceous; the second, *b*, presenting irregular prisms; and the third, *c*, with regular columns, which are vertical on the banks of the Volant, where they rest on a horizontal base of gneiss, but which are inclined at an angle of 45° at *g*, and then horizontal at *f*, their position having been every where determined, according to the law before mentioned, by the concave form of the original valley.

In the annexed figure (384.) a view is given of some of the inclined and curved columns which present themselves on the sides of the valleys in the hilly region north of Vicenza, in Italy, and at the foot of the higher Alps.* Unlike those of the Vivarais, last mentioned, the basalt of this coun-



Columnar basalt in the Vicentin.
(Fortis.)

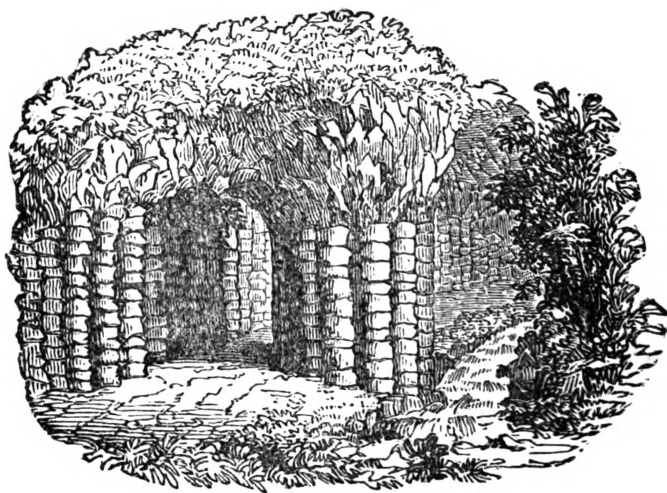
* Fortis, Mém. sur l'Hist. Nat. de l'Italie, tom. i. p. 233. plate 7.

try was evidently submarine, and the present valleys have since been hollowed out by denudation.

The columnar structure is by no means peculiar to the trap rocks in which hornblende or augite predominate ; it is also observed in clinkstone, trachyte, and other felspathic rocks of the igneous class, although in these it is rarely exhibited in such regular polygonal forms.

It has been already stated that basaltic columns are often divided by cross joints. Sometimes each segment, instead of an angular, assumes a spheroidal form, so that a pillar is made up of a pile of balls, usually flattened, as in the Cheese-grotto at Bertrich-Baden, in the Eifel, near the Moselle. (Fig. 385.) The basalt, there, is part of

Fig. 385.



Basaltic pillars of the Kasegrotte, Bertrich-Baden, half way between Treves and Coblenz. Height of grotto, from 7 to 8 feet.

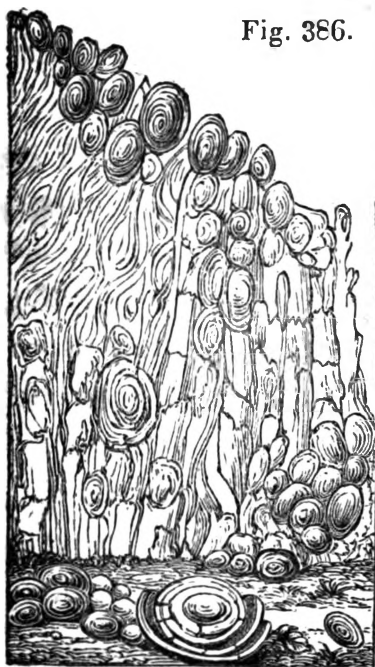
a small stream of lava, from 30 to 40 feet thick, which has proceeded from one of several volcanic

craters, still extant, on the neighbouring heights. The position of the lava bordering the river in this valley, might be represented by a section like that already given at Fig. 383. p. 228., if we merely supposed inclined strata of slate and the argillaceous sandstone called greywacké to be substituted for gneiss.

In some masses of decomposing greenstone, basalt, and other trap rocks, the globular structure is so conspicuous that the rock has the appearance of a heap of large cannon balls.

A striking example of this structure occurs in a resinous trachyte or pitchstone-porphyry in one of the Ponza islands, which rise from the Mediterranean, off the coast of Terracina and Gaieta.

Fig. 386.



Globiform pitchstone. Chiaja di Luna, Isle of Ponza. (Scrope.)

The globes vary from a few inches to three feet in diameter, and are of an ellipsoidal form (see Fig. 386.). The whole rock is in a state of decomposition, "and when the balls," says Mr. Scrope, "have been exposed a short time to the weather, they scale off at a touch into numerous concentric coats, like those of a bulbous root, inclosing a compact nucleus. The laminae

of this nucleus have not been so much loosened by decomposition ; but the application of a ruder blow will produce a still further exfoliation.” *

A fissile texture is occasionally assumed by clinkstone and other trap rocks, so that they have been used for roofing houses. Sometimes the prismatic and slaty structure is found in the same mass. The causes which give rise to such arrangements are very obscure, but are supposed to be connected with changes of temperature during the cooling of the mass, as will be pointed out in the sequel. (See Chap. 34.)

Relation of trappean rocks to the products of active volcanos.

When we reflect on the changes above described in the strata near their contact with trap dikes, and consider how great is the analogy in composition and structure of the rocks called trappean and the lavas of active volcanos, it seems difficult at first to understand how so much doubt could have prevailed for half a century as to whether trap was of igneous or aqueous origin. To a certain extent, however, there was a real distinction between the trappean formations and those to which the term volcanic was almost exclusively confined. The trappean rocks first

* Scrope, Geol. Trans., vol. ii. p. 205. Second Series.

studied in the north of Germany, and in Norway, France, Scotland, and other countries, were either such as had been formed entirely under deep water, or had been injected into fissures and intruded between strata, and which had never flowed out in the air, or over the bottom of a shallow sea. When these products, therefore, of submarine or subterranean igneous action were contrasted with loose cones of scoriæ, tuff, and lava, or with narrow streams of lava in great part scoriaceous and porous, such as were observed to have proceeded from Vesuvius and Etna, the resemblance seemed remote and equivocal. It was, in truth, like comparing the roots of a tree with its leaves and branches, which, although they belong to the same plant, differ in form, texture, colour, mode of growth, and position. The external cone, with its loose ashes and porous lava, may be likened to the light foliage and branches, and the rocks concealed far below, to the roots. But it is enough to say of the volcano,

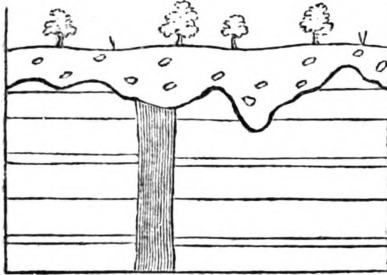
“quantum vertice in auras

Ætherias, tantum radice in Tartara tendit,”

for its roots do literally reach downwards to Tartarus, or to the regions of subterranean fire ; and what is concealed far below, is probably always more important in volume and extent than what is visible above ground.

We have already stated how frequently dense masses of strata have been removed by denudation from wide areas (see Chap. VI.); and this fact prepares us to expect a similar destruction of whatever may once have formed the uppermost part of ancient submarine or subærial volcanos, more especially as those superficial parts are always of the lightest and most perishable materials. The abrupt manner in which dikes of trap usually terminate at the surface (see Fig. 387.), and the water-worn pebbles of trap in the alluvium which covers the dike, prove incontestably that whatever was uppermost in these formations has

Fig. 387.



Strata intersected by a trap dike, and covered with alluvium.

been swept away. It is easy, therefore, to conceive that what is gone in regions of trap may have corresponded to what is now visible in active volcanos.

It will be seen in the following chapters, that in the earth's crust there are volcanic tuffs of all ages, containing marine shells, which bear witness to eruptions at many successive geological periods. These tuffs, and the associated trappean rocks, must not be compared to lava and scorix which had cooled in the open air. Their counterparts must be sought in the products of modern submarine volcanic erup-

tions. If it be objected that we have no opportunity of studying these last, it may be answered, that subterranean movements have caused, almost everywhere in regions of active volcanos, great changes in the relative level of land and sea, in times comparatively modern, so as to expose to view the effects of volcanic operations at the bottom of the sea.

Thus, for example, the recent examination of the igneous rocks of Sicily, especially those of the Val di Noto, has proved that all the more ordinary varieties of European trap have been there produced under the waters of the sea, at a modern period; that is to say, since the Mediterranean has been inhabited by a great proportion of the existing species of testacea.

These igneous rocks of the Val di Noto, and the more ancient trappean rocks of Scotland and other countries, differ from subaerial volcanic formations in being more compact and heavy, and in forming sometimes extensive sheets of matter intercalated between marine strata, and sometimes stratified conglomerates, of which the rounded pebbles are all trap. They differ also in the absence of regular cones and craters, and in the want of conformity of the lava to the lowest levels of existing valleys.

It is highly probable, however, that insular cones did exist in some parts of the Val di Noto:

and that they were removed by the waves, in the same manner as the cone of Graham Island, in the Mediterranean, was swept away in 1831, and that of Nyöe, off Iceland, in 1783. All that would remain in such cases, after the bed of the sea has been upheaved and laid dry, would be dikes and shapeless masses of igneous rock, cutting through sheets of lava which may have spread over the level bottom of the sea, and strata of tuff, formed of materials first scattered far and wide by the winds and waves, and then deposited. Trap conglomerates also, to which the action of the waves must give rise during the denudation of such volcanic islands, will emerge from the deep whenever the bottom of the sea becomes land.*

The proportion of volcanic matter which is originally submarine must always be very great, as those volcanic vents which are not entirely beneath the sea, are almost all of them in islands, or, if on continents, near the shore. This may explain why extended sheets of trap so often occur, instead of narrow threads, like lava streams. For, a multitude of causes tend, near the land, to reduce the bottom of the sea to a nearly uniform level,—the sediment of rivers,—materials transported by the waves and currents of the sea from

* See *Princ. of Geol., Index*, "Graham Island," "Nyöe," "Conglomerates, volcanic," &c.

wasting cliffs, — showers of sand and scoriæ ejected by volcanos, and scattered by the wind and waves. When, therefore, lava is poured out on such a surface, it will spread far and wide in every direction in a liquid sheet, which may afterwards, when raised up, form the tabular capping of the land.

As to the absence of porosity in the trappean formations, the appearances are in a great degree deceptive, for all amygdaloids are, as already explained, porous rocks, into the cells of which mineral matter, such as silex, carbonate of lime, and other ingredients, have been subsequently introduced. (See p. 200.)

In the Little Cumbray, one of the Western Islands, near Arran, the amygdaloid sometimes contains elongated cavities filled with brown spar; and when the nodules have been washed out, the interior of the cavities is glazed with the vitreous varnish so characteristic of the pores of slaggy lavas. Even in some parts of this rock which are excluded from air and water, the cells are empty, and seem to have always remained in this state, and are therefore undistinguishable from some modern lavas.*

Dr. MacCulloch, after examining with great attention these and the other igneous rocks of

* MacCulloch, West. Isl., vol. ii. p. 487.

Scotland, observes, "that it is a mere dispute about terms, to refuse to the ancient eruptions of trap the name of submarine volcanos; for they are such in every essential point, although they no longer eject fire and smoke."* The same author also considers it not improbable that some of the volcanic rocks of the same country may have been poured out in the open air.†

Although the principal component minerals of subaerial lavas are the same as those of intrusive trap, and both the columnar and globular structure are common to both, there are, nevertheless, some volcanic rocks which never occur as lava, such as greenstone, clinkstone, the more crystalline porphyries, and all those traps in which quartz and mica frequently appear as constituent parts. In short, the intrusive trap rocks, forming the intermediate step between lava and the plutonic rocks, depart in their characters from lava in proportion as they approximate to granite.

These views respecting the relations of the volcanic and trap rocks will be better understood when the reader has studied, in the 32nd chapter, what is said of the plutonic formations.

* Syst. of Geol., vol. ii. p. 114. † Ibid.

CHAPTER XXIX.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS.

Tests of relative age of volcanic rocks — Test by superposition and intrusion — Dike of Quarrington Hill, Durham — Test by alteration of rocks in contact — Test by organic remains — Test of age by mineral character — Test by included fragments — Volcanic rocks of the Post-Pliocene period — Basalt of Bay of Trezza in Sicily — Post-Pliocene volcanic rocks near Naples — Dikes of Somma — Igneous formations of the Newer Pliocene period — Val di Noto in Sicily.

HAVING referred the sedimentary strata to a long succession of geological periods, we have next to consider how far the volcanic formations can be classed in a similar chronological order. The tests of relative age in this class of rocks are four : — 1st, superposition and intrusion, with or without alteration of the rocks in contact ; 2d, organic remains ; 3d, mineral character ; 4th, included fragments of older rocks.

Test by superposition, &c.—If a volcanic rock rest upon an aqueous deposit, the former must be the newest of the two, but the like rule does not hold good where the aqueous formation rests upon the volcanic, for we have already seen (p. 225.) that melted matter, rising from below, may penetrate a sedimentary mass without reaching the

surface, or may be forced in conformably between two strata, as *b* at *D* in the annexed figure (Fig. 388.), after which it may cool down and consolidate. Superposition, therefore, is not of the

Fig. 388.

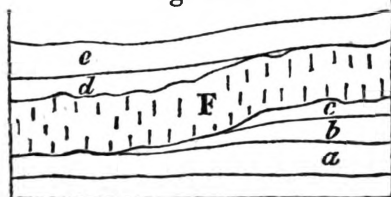


same value as a test of age in the unstratified volcanic rocks as in fossiliferous formations. We can only rely implicitly on this test where the volcanic rocks are contemporaneous, not where they are intrusive. Now they are said to be contemporaneous if produced by volcanic action, which was going on simultaneously with the deposition of the strata with which they are associated. Thus in the section at *D* (Fig. 388.), we may perhaps ascertain that the trap *b* flowed over the fossiliferous bed *c*, and that, after its consolidation, *a* was deposited upon it, *a* and *c* both belonging to the same geological period. But if the stratum *a* be altered by *b* at the point of contact, we must then conclude the trap to have been intrusive, or if, in pursuing *b* for some distance, we find at length that it cuts through the stratum *a*, and then overlies it.

We may, however, be easily deceived in supposing a volcanic rock to be intrusive, when in reality it is contemporaneous, for a sheet of lava,

as it spreads over the bottom of the sea, cannot rest every where upon the same stratum, either because these have been denuded, or because, if newly thrown down, they thin out in certain places, thus allowing the lava to cross their edges. Besides, the heavy igneous fluid will often, as it moves along, cut a channel into beds of soft mud and sand. Suppose the submarine lava *F* to have come in contact in this manner with the strata *a*, *b*, *c*, and that, after its consolidation, the strata *d*, *e*, are thrown down in a nearly horizontal position, yet so as to lie unconformably to *F*,

Fig. 389.

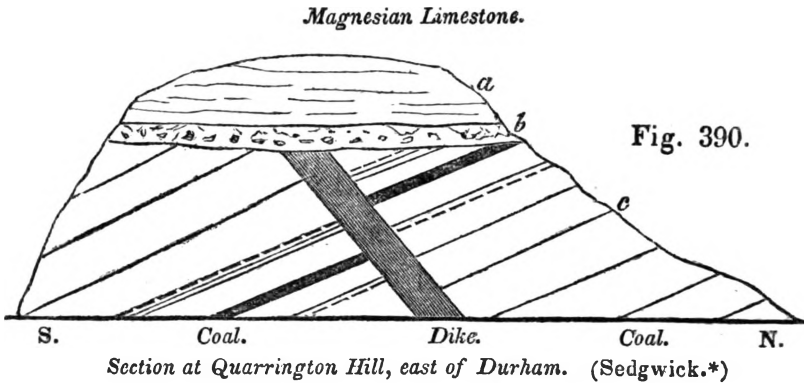


the appearance of subsequent intrusion will here be complete, although the trap is in fact contemporaneous.

We must, unless we find the strata *d* or *e* to have been altered at their junction, as if by heat, not therefore hastily infer that the rock *F* is intrusive.

When trap dikes were described in the preceding chapter, they were shown to be more modern than all the strata which they traverse. A basaltic dike at Quarrington Hill, near Durham, passes through Coal-measures, the strata of which are inclined, and shifted so that those on the north side of the dike are 24 feet above the level of the corresponding beds on the south side (see section, fig. 390.). But the horizontal

beds of overlying New Red Sandstone and Magnesian Limestone are not cut through by the



a. Magnesian Limestone. *b.* Lower New Red Sandstone.
c. Coal strata.

dike. Now here the Coal-measures were not only deposited, but had subsequently been disturbed, fissured, and shifted, before the fluid trap now forming the dike was introduced into a rent. It is also clear that some of the upper edges of the coal strata, together with the upper part of the dike, had been subsequently removed by denudation before the lower New Red Sandstone and Magnesian Limestone were superimposed.

* This illustration, for which I am indebted to Professor Sedgwick, is substituted for one given in the first edition, p. 470., which had been taken from the *Geol. Trans.*, vol. iv., where a dike is incorrectly represented at Cullercoats, Northumberland. At that spot, which I have since visited, there is no trap dike, but only a great fault. See Sedgwick, *Cambridge Trans.*

Even in this case, however, although the date of the volcanic eruption is brought within narrow limits, it cannot be defined with precision ; it may have happened either at the close of the Carboniferous period, or early in that of the lower New Red Sandstone, or between these two periods, when the state of the animate creation and the physical geography of Europe were gradually changing from the type of the Carboniferous era to that of the lower New Red formation.

The test of age by superposition is strictly applicable to all stratified volcanic tuffs, according to the rules as already explained in the case of other sedimentary deposits. (See Vol. I. p. 197.)

Test of age by organic remains.—We have seen how, in the vicinity of active volcanos, scoriæ, pumice, fine sand, and fragments of rock are thrown up into the air, and then showered down upon the land, or into neighbouring lakes or seas. In the tuffs so formed, shells, corals, or any other durable organic bodies which may happen to be strewed over the bottom of a lake or sea will be imbedded, and thus continue as permanent memorials of the geological period when the volcanic eruption occurred. Tufaceous strata thus formed in the neighbourhood of Vesuvius, Etna, Stromboli, and other volcanos now active in islands or near the sea, may give information of the relative age of these tuffs at some remote future

period when the fires of these mountains are extinguished. By such evidence we can distinctly establish the coincidence in age of volcanic rocks, and the different primary, secondary, and tertiary fossiliferous strata already considered.

The tuffs now alluded to are not exclusively marine, but include, in some places, fresh-water shells; in others, the bones of terrestrial quadrupeds. The diversity of organic remains in formations of this nature is perfectly intelligible, if we reflect on the wide dispersion of ejected matter during late eruptions, such as that of the volcano of Coseguina, in the province of Nicaragua, January 19, 1835. Hot cinders and fine scoriæ were then cast up to a vast height, and covered the ground as they fell to the depth of more than ten feet, and for a distance of eight leagues from the crater in a southerly direction. Birds, cattle, and wild animals were scorched to death in great numbers, and buried in these ashes. Some volcanic dust fell at Chiapa, upwards of 1200 miles to windward of the volcano, a striking proof of a counter current in the upper region of the atmosphere; and some on Jamaica, about 700 miles distant to the north-east. In the sea, also, at the distance of 1100 miles from the point of eruption, Captain Eden of the *Conway* sailed 40 miles through floating pumice,

among which were some pieces of considerable size.*

Test of age by mineral composition.—As sediment of homogeneous composition, when discharged from the mouth of a large river, is often deposited simultaneously over a wide space, so a particular kind of lava flowing from a crater during one eruption, may spread over an extensive area; as in Iceland in 1783, when the melted matter, pouring from Skaptar Jokul, flowed in streams in opposite directions, and caused a continuous mass, the extreme points of which were 90 miles distant from each other. This enormous current of lava varied in thickness from 100 feet to 600 feet, and in breadth from that of a narrow river gorge to 15 miles.† Now, if such a mass should afterwards be divided into separate fragments by denudation, we might still perhaps identify the detached portions by their similarity in mineral composition. Nevertheless, this test will not always avail the geologist; for, although there is usually a prevailing character in lava emitted during the same eruption, and even in the successive currents flowing from the same volcano, still, in many cases, the different parts even of one lava-stream, or,

* Caldcleugh, Phil. Trans., 1836, p. 27., and Official Documents of Nicaragua.

† See Principles, *Index*, "Skaptar Jokul."

as before stated, of one continuous mass of trap, vary so much in mineral composition and texture as to render these characters of minor importance when compared to their value in the chronology of the fossiliferous rocks.

It will, however, be seen in the description which follows, of the European trap rocks of different ages, that they had often a peculiar lithological character, resembling the differences before remarked as existing between the modern lavas of Vesuvius, Etna, and Chili. (See p. 202.)

It has been remarked that in Auvergne, the Eifel, and other countries where trachyte and basalt are both present, the trachytic rocks are for the most part older than the basaltic. These rocks do, indeed, sometimes alternate partially, as in the volcano of Mont Dor, in Auvergne ; but the great mass of trachyte occupies in general an inferior position, and is cut through and overflowed by basalt. It can by no means be inferred that trachyte predominated greatly at one period of the earth's history and basalt at another, for we know that trachytic lavas have been formed at many successive periods, and are still emitted from many active craters ; but it seems that in each region, where a long series of eruptions have occurred, the more felspathic lavas have been first emitted, and the escape of the more augitic kinds has followed. The hypothesis suggested by

Mr. Scrope may, perhaps, afford a solution of this problem. The minerals, he observes, which abound in basalt are of greater specific gravity than those composing the felspathic lavas; thus, for example, hornblende, augite, and olivine are each more than three times the weight of water; whereas common felspar, albite, and Labrador felspar, have each scarcely more than $2\frac{1}{2}$ times the specific gravity of water; and the difference is increased in consequence of there being much more iron in a metallic state in basalt and greenstone than in trachyte and other felspathic lavas and traps. If, therefore, a large quantity of rock be melted up in the bowels of the earth by volcanic heat, the denser ingredients of the boiling fluid will sink to the bottom, and the lighter remaining above will be first propelled upwards to the surface by the expansive power of gases. Those materials, therefore, which occupied the lowest place in the subterranean reservoir will always be emitted last, and take the uppermost place on the exterior of the earth's crust.

Test by included fragments.—We may sometimes discover the relative age of two trap rocks, or of an aqueous deposit and the trap on which it rests, by finding fragments of one included in the other, in cases such as those before alluded to, where the evidence of superposition alone would be insufficient. It is also not uncommon to find

conglomerates almost exclusively composed of rolled pebbles of trap, associated with stratified rocks in the neighborhood of masses of intrusive trap. If the pebbles agree generally in mineral character with the latter, we are then enabled to determine the age of the intrusive rock by knowing that of the fossiliferous strata associated with the conglomerate. The origin of such conglomerates is explained by observing the shingle beaches composed of trap pebbles in modern volcanic islands, or at the base of Etna.

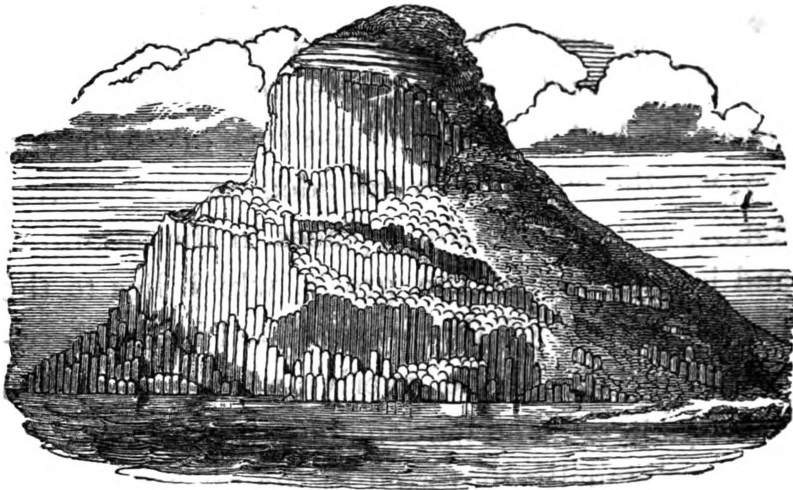
Post-Pliocene Period (including the Recent).— I shall now select examples of contemporaneous volcanic rocks of successive geological periods, to show that igneous causes have been in activity in all past ages of the world, and that they have been ever shifting the places where they have broken out at the earth's surface.

One portion of the lavas, tuffs, and trap-dikes of Etna, Vesuvius, and the island of Ischia, has been produced within the historical era; another, and a far more considerable part, originated at times immediately antecedent, when the waters of the mediterranean were already inhabited by the existing species of testacea. By consulting the map (plate 2.) the reader will see that the southern and eastern flanks of Etna are skirted by a fringe of sedimentary deposits, as at Aderno, Trezza, and other places. These are designated

in the map as Newer Pliocene, alternating with volcanic. The strata are marine ; but fossils have scarcely yet been collected in sufficient number to enable us to decide whether they were formed during the Post-Pliocene, or at the close of the Newer Pliocene period. Of 65 species of shells which I procured near Trezza, it was scarcely possible to distinguish any from species now living in the neighbouring sea.

The Cyclopiian Islands, called by the Sicilians Dei Faraglioni, in the sea cliffs of which these

Fig. 391



*View of the Isle of Cyclops in the bay of Trezza.**

beds and the associated volcanic rocks are laid open to view, are situated in the Bay of Trezza,

* This view of the Isle of Cyclops is from an original drawing by my friend Captain Basil Hall, R. N.

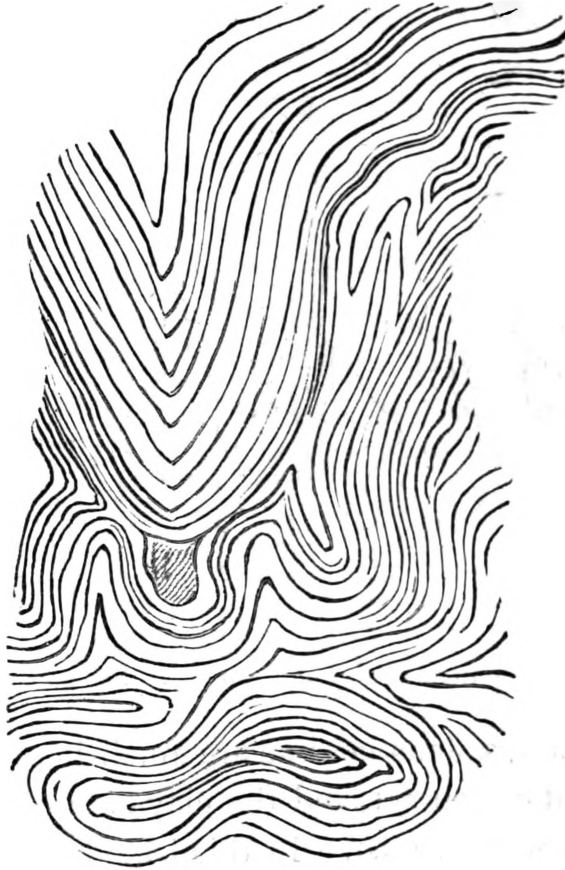
and may be regarded as the extremity of a promontory severed from the main land. Here numerous proofs are seen of submarine eruptions, by which the argillaceous and sandy strata were invaded and cut through, and tufaceous breccias formed. Inclosed in these breccias are many angular and hardened fragments of laminated clay in different states of alteration by heat, and intermixed with volcanic sands.

The loftiest of the Cyclopien islets, or rather rocks, is about two hundred feet in height, the summit being formed of a mass of stratified clay, the laminæ of which are occasionally subdivided by thin arenaceous layers. These strata dip to the N. W., and rest on a mass of columnar lava (see Fig. 391.), in which the tops of the pillars are weathered, and so rounded as to be often hemispherical. In some places in the adjoining and largest islet of the group, which lies to the north-eastward of that represented in the drawing (Fig. 391.), the overlying clay has been greatly altered, and hardened by the igneous rock, and occasionally contorted in the most extraordinary manner; yet the lamination has not been obliterated, but, on the contrary, rendered much more conspicuous, by the indurating process.

The annexed wood cut (Fig. 392.) is a careful representation of a portion of the altered rock, a few feet square, where the alternating thin

laminæ of sand and clay have put on the appearance which we often observe in some of the most contorted of the metamorphic schists.

Fig. 392.

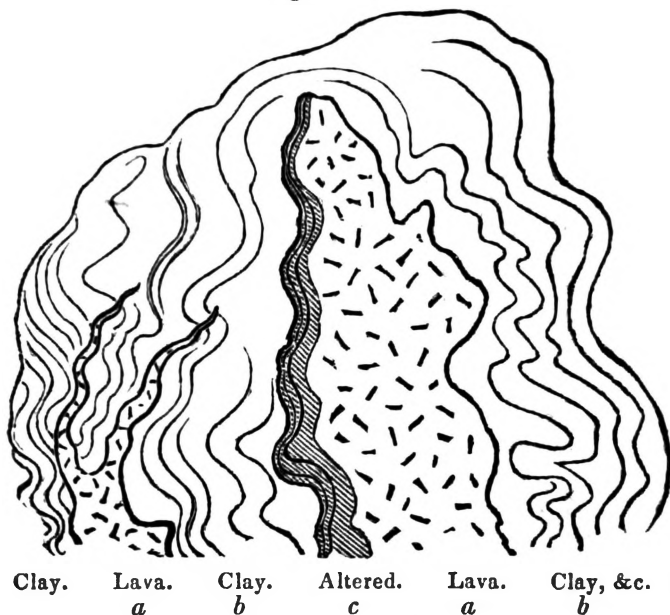


Contortions in the strata of the largest of the Cyclopiæ Islands.

A great fissure, running from east to west, nearly divides this larger island into two parts, and lays open its internal structure. In the section thus exhibited a dike of lava is seen, first cutting through an older mass of lava, and then penetrating the superincumbent tertiary strata.

In one place the lava ramifies and terminates in thin veins, from a few feet to a few inches in thickness (see Fig. 393.).

Fig. 393.



Newer Pliocene strata invaded by lava, Isle of Cyclops (horizontal section).

a. Lava. b. Laminated clay and sand. c. The same altered.

The arenaceous laminæ are much hardened at the point of contact, and the clays are converted into siliceous schist. In this island the altered rocks assume a honeycombed structure on their weathered surface, singularly contrasted with the smooth and even outline which the same beds present in their usual soft and yielding state.

The pores of the lava are sometimes coated, or entirely filled, with carbonate of lime, and with a zeolite resembling analcime, which has been called

cyclopite. The latter mineral has also been found in small fissures traversing the altered marl, showing that the same cause which introduced the minerals into the cavities of the lava, whether we suppose sublimation or aqueous infiltration, conveyed it also into the open rents of the contiguous sedimentary strata.

Post-Pliocene formations near Naples. — I have traced in the "Principles of Geology" the history of the changes which the volcanic region of Campania is known to have undergone during the last 2000 years. The aggregate effect of igneous operations during that period is far from insignificant, comprising as it does the formation of the modern cone of Vesuvius since the year 79, and the production of several minor cones in Ischia, together with that of Monte Nuovo in the year 1538. Lava currents have also flowed upon the land and along the bottom of the sea — volcanic sand, pumice, and scorix have been showered down so abundantly that whole cities were buried — tracts of the sea have been filled up or converted into shoals, and tufaceous sediment has been transported by rivers and land floods to the sea. There are also proofs during the same recent period of a permanent alteration of the relative levels of the land and sea in several places, and of the same tract having, near Puzzuoli, been alternately upheaved and depress-

ed to the amount of more than twenty feet. In connection with these convulsions, there are found, on the shores of the Bay of Baiæ, recent tufaceous strata filled with articles fabricated by the hands of man, and mingled with marine shells.

It was before stated in this work, that when we examine this same region it is found to consist largely of tufaceous strata, of a date anterior to human history or tradition, which are of such thickness as to constitute hills from 500 to more than 2000 feet in height. These strata, containing recent marine shells, alternate with distinct currents and sheets of lava which were of contemporaneous origin ; and we find that in Vesuvius itself, the ancient cone called Somma is of far greater volume than the modern cone, and is intersected by a far greater number of dikes. In contrasting this ancient part of the mountain with that of modern date, one principal point of difference is observed ; namely, the greater frequency in the older cone of fragments of altered sedimentary rocks ejected during eruptions. We may easily conceive that the first explosions would act with the greatest violence, rending and shattering whatever solid masses obstructed the escape of lava and the accompanying gases, so that great heaps of ejected pieces of rock would naturally occur in the tufaceous breccias formed by the earliest eruptions.

But when a passage had once been opened and an habitual vent established, the materials thrown out would consist of liquid lava, which would take the form of sand and scoriæ, or of angular fragments of such solid lavas as may have choked up the vent.

Among the fragments which abound in the tufaceous breccias of Somma, none are more common than a saccharoid dolomite, supposed to have been derived from an ordinary limestone altered by heat and volcanic vapours.

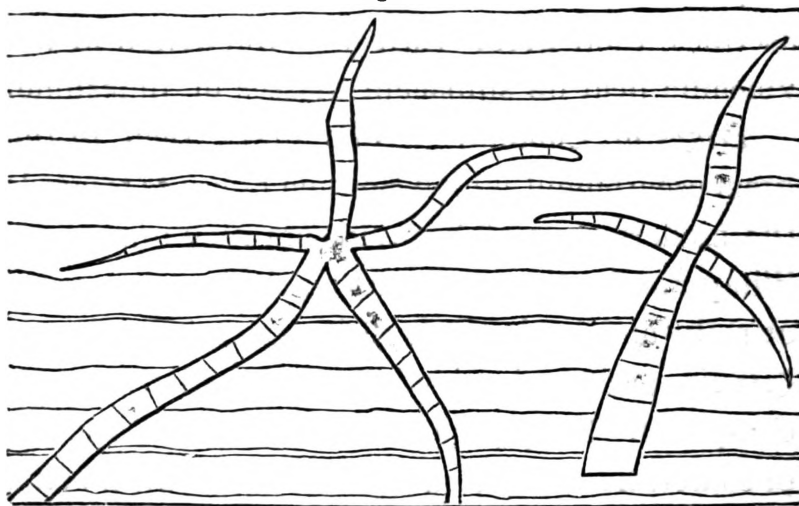
Carbonate of lime enters into the composition of so many of the simple minerals found in Somma, that M. Mitscherlich, with much probability, ascribes their great variety to the action of the volcanic heat on subjacent masses of limestone.

Dikes of Somma. — The dikes seen in the great escarpment which Somma presents towards the modern cone of Vesuvius are very numerous. They are for the most part vertical, and traverse at right angles the beds of lava, scoriæ, volcanic breccia, and sand, of which the ancient cone is composed. They project in relief several inches, or sometimes feet, from the face of the cliff, being extremely compact, and less destructible than the intersected tuffs and porous lavas. In vertical extent they vary from a few yards to 500 feet, and in breadth from one to twelve feet. Many of them cut all the inclined beds in the escarpment of Somma from top to bottom, others stop short

before they ascend above half way, and a few terminate at both ends, either in a point or abruptly. In mineral composition they scarcely differ from the lavas of Somma, the rock consisting of a base of leucite and augite, through which large crystals of augite and some of leucite are scattered.* Examples are not rare of one dike cutting through another, and in one instance a shift or fault is seen at the point of intersection.

In some cases, however, the rents seem to have been filled laterally, when the walls of the crater had been broken by star-shaped cracks, as seen in the accompanying wood cut (Fig. 394.).

Fig. 394.



Dikes or veins at the Punto del Nasone on Somma. (Necker.†)

* Consult the valuable memoir of M. L. A. Necker, *Mém. de la Soc. de Phys. et d'Hist. Nat. de Genève*, tom. ii. part i. Nov. 1822.

† From a drawing of M. Necker, in *Mém.* above cited.

But the shape of these rents is an exception to the general rule ; for nothing is more remarkable than the usual parallelism of the opposite sides of the dikes, which correspond almost as regularly as the two opposite faces of a wall of masonry. This character appears at first the more inexplicable, when we consider how jagged and uneven are the rents caused by earthquakes in masses of heterogeneous composition like those composing the cone of Somma. In explanation of this phenomenon, M. Necker refers us to Sir W. Hamilton's account of an eruption of Vesuvius in the year 1779, who records the following facts:—"The lavas, when they either boiled over the crater, or broke out from the conical parts of the volcano, constantly formed channels as regular as if they had been cut by art down the steep part of the mountain ; and, whilst in a state of perfect fusion, continued their course in those channels, which were sometimes full to the brim, and at other times more or less so, according to the quantity of matter in motion.

"These channels, upon examination after an eruption, I have found to be in general from two to five or six feet wide, and seven or eight feet deep. They were often hid from the sight by a quantity of scoriæ that had formed a crust over them ; and the lava having been conveyed in a covered way for some yards, came out fresh again

into an open channel. After an eruption I have walked in some of those subterraneous or covered galleries, which were exceedingly curious, the sides, top, and bottom *being worn perfectly smooth and even* in most parts, by the violence of the currents of the red-hot lavas which they had conveyed for many weeks successively.”*

Now, the walls of a vertical fissure through which lava has ascended in its way to a volcanic vent, must have been exposed to the same erosion as the sides of the channels before adverted to. The prolonged and uniform friction of the heavy fluid, as it is forced and made to flow upwards, cannot fail to wear and smooth down the surfaces on which it rubs, and the intense heat must melt all such masses as project and obstruct the passage of the incandescent fluid.

The texture of the Vesuvian dikes is different at the edges and in the middle. Towards the centre, observes M. Necker, the rock is larger grained, the component elements being in a far more crystalline state ; while at the edge the lava is sometimes vitreous, and always finer grained. A thin parting band, approaching in its character to pitchstone, occasionally intervenes on the contact of the vertical dike and intersected beds. M. Necker mentions one of these at the place called *Primo Monte*, in the *Atrio del Cavallo* ; and when

* Phil. Trans., vol. lxx., 1780.

on Somma, in 1828, I saw three or four others in different parts of the great escarpment. These phenomena are in perfect harmony with the results of the experiments of Sir James Hall and Mr. Gregory Watt, which have shown that a glassy texture is the effect of sudden cooling, and that, on the contrary, a crystalline grain is produced where fused minerals are allowed to consolidate slowly and tranquilly under high pressure.

It is evident that the central portion of the lava in a fissure would, during consolidation, part with its heat more slowly than the sides, although the contrast of circumstances would not be so great as when we compare the lava at the bottom and at the surface of a current flowing in the open air. In this case the uppermost part, where it has been in contact with the atmosphere, and where refrigeration has been most rapid, is always found to consist of scoriform, vitreous, and porous lava; while at a greater depth the mass assumes a more lithoidal structure, and then becomes more and more stony as we descend, until at length we are able to recognize with a magnifying glass the simple minerals of which the rock is composed. On penetrating still deeper, we can detect the constituent parts by the naked eye, and in the Vesuvian currents distinct crystals of augite and leucite become apparent.

The same phenomenon, observes M. Necker,

may readily be exhibited on a smaller scale, if we detach a piece of liquid lava from a moving current. The fragment cools instantly, and we find the surface covered with a vitreous coat, while the interior, although extremely fine-grained, has a more stony appearance.

It must, however, be observed, that although the lateral portions of the dikes are finer grained than the central, yet the vitreous parting layer before alluded to is rare in Vesuvius. This may, perhaps, be accounted for, as the above-mentioned author suggests, by the great heat which the walls of a fissure may acquire before the fluid mass begins to consolidate, in which case the lava, even at the sides, would cool very slowly. Some fissures, also, may be filled from above; and in this case the refrigeration at the sides would be more rapid than when the melted matter flowed upwards from the volcanic foci, in an intensely heated state. Mr. Darwin informs me that in St. Helena almost every dike has a vitreous selvage.

The rock composing the dikes both in the modern and ancient part of Vesuvius is far more compact than that of ordinary lava, for the pressure of a column of melted matter in a fissure greatly exceeds that in an ordinary stream of lava; and pressure checks the expansion of those gases which gave rise to vesicles in lava.

There is a tendency in almost all the Vesuvian

dikes to divide into horizontal prisms, a phenomenon in accordance with the formation of vertical columns in horizontal beds of lava ; for in both cases the divisions which gave rise to the prismatic structure are at right angles to the cooling surfaces.

Newer Pliocene period — Val di Noto.— I have already alluded on more than one occasion (see p. 235. and Vol. I. p. 293.) to the igneous rocks which are associated with a great marine formation of limestone, sand, and marl, in the southern part of Sicily, as at Vizzini and other places. (See Map, plate 2.) In this formation, which was shown to belong to the Newer Pliocene period, large beds of oysters and corals repose upon lava, and are unaltered at the point of contact. In other places we find dikes of igneous rock intersecting the fossiliferous beds, and converting the clays into siliceous schist, the laminæ being contorted and shivered into innumerable fragments at the junction, as near the town of Vizzini.

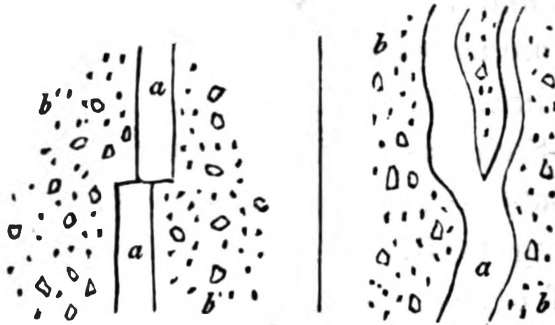
The volcanic formations of the Val di Noto usually consist of the most ordinary variety of basalt, with or without olivine. The rock is sometimes compact, often very vesicular. The vesicles are occasionally empty, both in dikes and currents, and are in some localities filled with calcareous spar, arragonite, and zeolites. The structure is, in some places, spheroidal ; in others,

though rarely, columnar. I found dikes of amygdaloid, wacké, and prismatic basalt, intersecting the limestone at the bottom of the hollow called Gozzo degli Martiri, below Melilli.

Dikes. — Dikes of vesicular and amygdaloidal lava are also seen traversing marine tuff or peperino, west of Palagonia, some of the pores of the

Fig. 395.

Fig. 396.



Ground plan of dikes near Palagonia.

a. Lava.

b. Peperino, consisting of volcanic sand, mixed with fragments of lava and limestone.

lava being empty, while others are filled with carbonate of lime. In such cases, we may suppose the peperino to have resulted from showers of volcanic sand and scoriæ, together with fragments of limestone thrown out by a submarine explosion, similar to that which gave rise to Graham Island in 1831. When the mass was, to a certain degree, consolidated, it may have been rent open, so that the lava ascended through fissures, the walls of which were perfectly even

and parallel. After the melted matter that filled the rent in Fig. 395. had cooled down, it must have been fractured and shifted horizontally by a lateral movement.

In the second figure, No. 396., the lava has more the appearance of a vein which forced its way through the peperino. It is highly probable that similar appearances would be seen, if we could examine the floor of the sea in that part of the Mediterranean where the waves have recently washed away the new volcanic island; for when a superincumbent mass of ejected fragments has been removed by denudation, we may expect to see sections of dikes traversing tuff, or, in other words, sections of the channels of communication by which the subterranean lavas reached the surface.

CHAPTER XXX.

ON THE DIFFERENT AGES OF THE VOLCANIC ROCKS —
continued.

Volcanic rocks of the Older Pliocene period — Tuscany — Rome — Volcanic region of Olot in Catalonia — Cones and lava-currents — Ravines and ancient gravel-beds — Jets of air called Bufadors — Age of the Catalonian volcanos — Miocene period — Brown coal of the Eifel and contemporaneous trachitic breccias — Age of the Brown coal — Peculiar characters of the volcanos of the upper and lower Eifel — Lake craters — Trass — Hungarian volcanos.

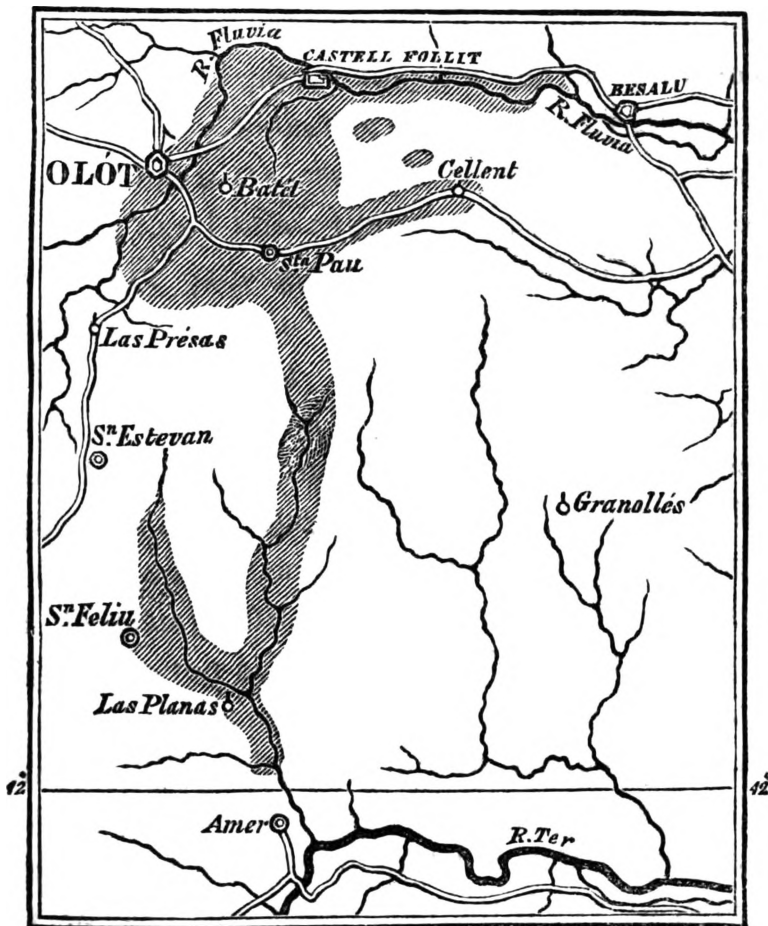
Older Pliocene period—Tuscany.—IN Tuscany, as at Radicofani, Viterbo, and Aquapendente, and in the Campagna di Roma, submarine volcanic tuffs are interstratified with the Older Pliocene strata of the Subapennine hills, in such a manner as to leave no doubt that they were the products of eruptions which occurred when the shelly marls and sands of the Subapennine hills were in the course of deposition.

Catalonia.—Geologists are far from being able, as yet, to assign to each of the volcanic groups scattered over Europe a precise chronological place in the tertiary series ; but I shall describe

here, as probably referable to the Older Pliocene period, a district of extinct volcanos near Olot, in the north of Spain, which is little known, and which I visited in the summer of 1830.

The whole extent of country occupied by volcanic products in Catalonia is not more than

Fig. 397.



Volcanic district of Catalonia.

fifteen geographical miles from north to south, and about six from east to west. The vents of

eruption range entirely within a narrow band running north and south ; and the branches, which are represented as extending eastward in the map, are formed simply of two lava-streams — those of Castell Follit and Cellent.

Dr. Maclure, the American geologist, was the first who made known the existence of these volcanos ;* and, according to his description, the volcanic region extended over twenty square leagues, from Amer to Massanet. I searched in vain in the environs of Massanet, in the Pyrenees, for traces of a lava-current ; and I can say, with confidence, that the adjoining map gives a correct view of the true area of the volcanic action.

Geological structure of the district. — The eruptions have burst entirely through secondary rocks, composed in great part of grey and greenish sandstone and conglomerate, with some thick beds of nummulitic limestone. The conglomerate contains pebbles of quartz, limestone, and Lydian stone. The limestone is not only replete with nummulites, but occasionally includes oysters, pectens, and other shells. This system of rocks is very extensively spread throughout Catalonia ; one of its members being a red sandstone, to which the celebrated salt-rock of Cardona is subordinate. The whole is now gen-

* Maclure, Journ. de Phys., vol. lxvi. p. 219., 1808 ; cited by Daubeny, Description of Volcanos, p. 24.

erally considered as belonging to the age of our green-sand and chalk.

Near Amer, in the Valley of the Ter, on the southern borders of the region delineated in the map, primary rocks are seen, consisting of gneiss, mica-schist, and clay slate. They run in a line nearly parallel to the Pyrenees, and throw off the secondary strata from their flanks, causing them to dip to the north and north-west. This dip, which is towards the Pyrenees, is connected with a distinct axis of elevation, and prevails through the whole area described in the map, the inclination of the beds being sometimes at an angle of between 40 and 50 degrees.

It is evident that the physical geography of the country has undergone no material change since the commencement of the era of the volcanic eruptions, except such as has resulted from the introduction of new hills of scoriæ, and currents of lava upon the surface. If the lavas could be remelted and poured out again from their respective craters, they would descend the same valleys in which they are now seen, and re-occupy the spaces which they at present fill. The only difference in the external configuration of the fresh lavas would consist in this, that they would nowhere be intersected by ravines, or exhibit marks of erosion by running water.

Volcanic cones and lavas. — There are about

fourteen distinct cones with craters in this part of Spain, besides several points whence lavas may have issued; all of them arranged along a narrow line running north and south, as will be seen in the map. The greatest number of perfect cones are in the immediate neighbourhood of Olot, some of which are represented in the annexed plate (Pl. VII.); and the level plain on which that town stands has clearly been produced by the flowing down of many lava-streams from those hills into the bottom of a valley, probably once of considerable depth, like those of the surrounding country.

In this plate an attempt is made to represent by colours the different geological formations of which the country is composed.* The blue line of mountains in the distance are the Pyrenees, which are to the north of the spectator, and consist of hypogene and ancient fossiliferous rocks. In front of these are the secondary formations described in this chapter, coloured grey. Different shades of this colour are introduced, to express various distances. The flank of the hill, in the foreground, called Costa de Pujou, is composed partly of secondary rocks, and partly of volcanic, the red colour expressing lava and scorïæ.

* This view is taken from a sketch which I made on the spot in 1830.



1. St Michel.

2. Monte Oliveto.

3. Montescopa.

4. Puig Sacorrena.

5. Gradonada.

View of the Colca v. around Elot in Catalonia.

The Fluvia, which flows near the town of Olot, has cut to the depth of only 40 feet through the lavas of the plain before mentioned. The bed of the river is hard basalt ; and at the bridge of Santa Madalena are seen two distinct lava-currents, one above the other, separated by a horizontal bed of scoriæ eight feet thick.

In one place, to the south of Olot, the even surface of the plain is broken by a mound of lava, called the "Bosque de Tosca," the upper part of which is scoriaceous, and covered with enormous heaps of fragments of basalt more or less porous. Between the numerous hummocks thus formed are deep cavities, having the appearance of small craters. The whole precisely resembles some of the modern currents of Etna, or that of Côme, near Clermont ; the last of which, like the Bosque de Tosca, supports only a scanty vegetation.

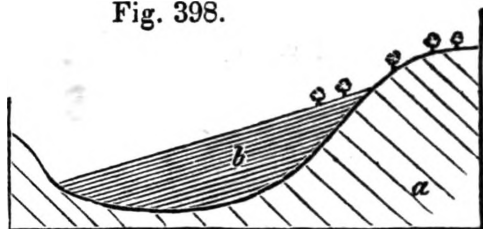
Most of the Catalonian volcanos are as entire as those in the neighbourhood of Naples, or on the flanks of Etna. One of these figured in the plate, called Montsacopa, is of a very regular form, and has a circular depression or crater at the summit. It is chiefly made up of red scoriæ, undistinguishable from that of the minor cones of Etna. The neighbouring hills of Olivet and Garrinada, also figured in the plate, are of similar composition and shape. The largest

crater of the whole district occurs farther to the east of Olot, and is called Santa Margarita. It is 455 feet deep, and about a mile in circumference. Like Astroni, near Naples, it is richly covered with wood, wherein game of various kinds abounds.

Although the volcanos of Catalonia have broken out through sandstone, shale, and limestone, as have those of the Eifel, in Germany, to be described in the sequel, there is a remarkable difference in the nature of the ejections composing the cones in these two regions. In the Eifel, the quantity of pieces of sandstone and shale thrown out from the vents is often so immense as far to exceed in volume the scorix, pumice, and lava ; but I sought in vain in the cones near Olot for a single fragment of any extraneous rock ; and Don Francisco Bolos, an eminent botanist of Olot, informs me that he has never been able to detect any. Volcanic sand and ashes are not confined to the cones, but have been sometimes scattered by the wind over the country, and drifted into narrow valleys, as is seen between Olot and Cellent, where the annexed section is exposed. The light cindery volcanic matter rests in thin regular layers, just as it alighted on the slope formed by the solid conglomerate. No flood could have

passed through the valley since the scorïæ fell, or these would have been for the most part removed.

Fig. 398.

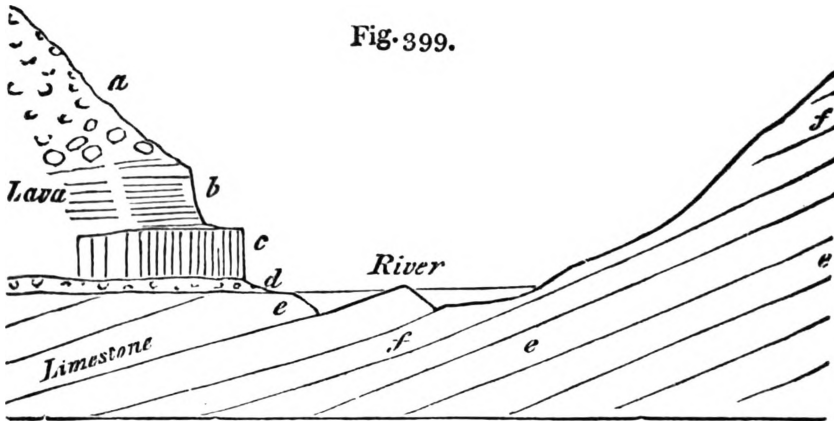


a. secondary conglomerate.

b. thin seams of volcanic sand and scorïæ.

The currents of lava in Catalonia, like those of Auvergne, the Vivarais, Iceland, and all mountainous countries, are of considerable depth in narrow defiles, but spread out into comparatively thin sheets in places where the valleys widen. If a river has flowed on nearly level ground, as in the great plain near Olot, the water has only excavated a channel of slight depth ; but where the declivity is great, the stream has cut a deep section, sometimes by penetrating directly through the central part of a lava-current, but more frequently by passing between the lava and the secondary rock which bounds the valley. Thus, in the accompanying section, at the bridge of Cellent, six miles east of Olot, we see the lava on one side of the small stream ; while the inclined stratified rocks constitute the channel and opposite bank. The upper part of the lava at that

place, as is usual in the currents of Etna and Vesuvius, is scoriaceous ; farther down it becomes less porous, and assumes a spheroidal structure ;



Section above the bridge of Cellent.

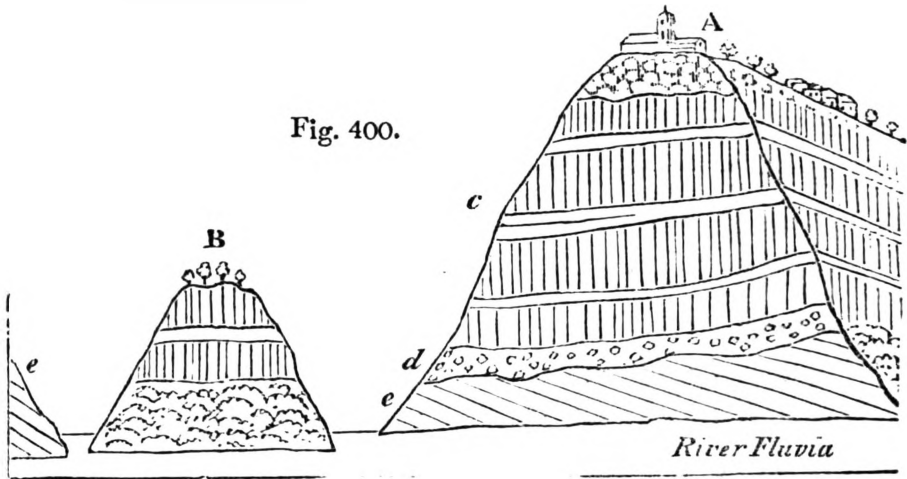
- a. Scoriaceous lava. d. Scoria, vegetable soil, and alluvium.
 b. Schistose basalt. e. Nummulitic limestone.
 c. Columnar basalt. f. Micaceous grey sandstone.

still lower it divides in horizontal plates, each about two inches in thickness, and is more compact. Lastly, at the bottom is a mass of prismatic basalt about five feet thick. The vertical columns often rest immediately on the subjacent secondary rocks ; but there is sometimes an intervention of such sand and scoriæ as cover the country during volcanic eruptions, and which when unprotected, as here, by superincumbent lava, is washed away from the surface of the land. Sometimes, the bed, *d*, contains a few pebbles and angular fragments of rock ; in other places fine earth, which may have constituted an ancient vegetable soil.

In several localities, beds of sand and ashes are interposed between the lava and subjacent stratified rock, as may be seen if we follow the course of the lava-current which descends from Las Planas towards Amer, and stops two miles short of that town. The river there has often cut through the lava, and through eighteen feet of underlying limestone. Occasionally an alluvium, several feet thick, is interspersed between the igneous and marine formation ; and it is interesting to remark that in this, as in other beds of pebbles occupying a similar position, there are no rounded fragments of lava ; whereas in the most modern gravel-beds of rivers of this country, volcanic pebbles are abundant.

The deepest excavation made by a river through lava, which I observed in this part of Spain, is that seen in the bottom of a valley near San Feliu de Palleróls, opposite the Castell de Stollés. The lava there has filled up the bottom of a valley, and a narrow ravine has been cut through it to the depth of one hundred feet. In the lower part the lava has a columnar structure. A great number of ages were probably required for the erosion of so deep a ravine ; but we have no reason to infer that this current is of higher antiquity than those of the plain near Olot. The fall of the ground, and consequent velocity of the stream, being in this case greater, a more con-

siderable volume of rock may have been removed in the same time.



Section at Castell Follit.

- A. Church and town of Castell Follit, overlooking precipices of basalt.
- B. Small island, on each side of which branches of the river Teronel flow to meet the Fluvia.
- c. Precipice of basaltic lava, chiefly columnar, about 130 feet in height.
- d. Ancient alluvium, underlying the lava current.
- e. Inclined strata of secondary sandstone.

I shall describe one more section to elucidate the phenomena of this district. A lava-stream, flowing from a ridge of hills on the east of Olot, descends a considerable slope, until it reaches the valley of the river Fluvia. Here, for the first time, it comes in contact with running water, which has removed a portion, and laid open its internal structure in a precipice about 130 feet in height, at the edge of which stands the town of Castell Follit.

By the junction of the rivers Fluvia and Teronel the mass of lava has been cut away on two sides ; and the insular rock B (Fig.400.) has been left, which was probably never so high as the cliff A, as it may have constituted the lower part of the sloping side of the original current.

From an examination of the vertical cliffs, it appears that the upper part of the lava on which the town is built is scoriaceous, passing downwards into a spheroidal basalt ; some of the huge spheroids being no less than six feet in diameter. Below this is a more compact basalt with crystals of olivine. There are in all about four distinct ranges of prismatic basalt, separated by thinner beds not columnar, and some of which are schistose. The whole mass rests on alluvium, ten or twelve feet in thickness, composed of pebbles of limestone and quartz, but without any intermixture of igneous rocks ; in which circumstance alone it appears to differ from the modern gravel of the Fluvia.

Bufadors. — The volcanic rocks near Olot have often a cavernous structure, like some of the lavas of Etna ; and in many parts of the hill of Batet, in the environs of the town, the sound returned by the earth when struck, is like that of an arch-way. At the base of the same hill are the mouths of several subterranean caverns, about twelve in number, which are called in the

country "bufadors," from which a current of cold air issues during summer, but which in winter is said to be scarcely perceptible. I visited one of these bufadors in the beginning of August, 1830, when the heat of the season was unusually intense, and found a cold wind blowing from it; which may easily be explained, for as the external air, when rarefied by heat, ascends, the pressure of the colder and heavier air of the caverns in the interior of the mountain causes it to rush out to supply its place.

In regard to the age of these Spanish volcanos, attempts have been made to prove, that in this country, as well as in Auvergne and the Eifel, the earliest inhabitants were eye-witnesses to the volcanic action. In the year 1421, it is said, when Olot was destroyed by an earthquake, an eruption broke out near Amer, and consumed the town. The researches of Don Francisco Bolos have, I think, shown, in the most satisfactory manner, that there is no good historical foundation for the latter part of this story; and any geologist who has visited Amer must be convinced that there never was any eruption on that spot. It is true that, in the year above mentioned, the whole of Olot, with the exception of a single house, was cast down by an earthquake; one of those shocks which, at distant intervals during the last five centuries, have shaken the

Pyrenees, and particularly the country between Perpignan and Olot, where the movements, at the period alluded to, were most violent.

The annihilation of the town may, perhaps, have been due to the cavernous nature of the subjacent rocks; for Catalonia is beyond the line of those European earthquakes which have, within the period of history, destroyed towns throughout extensive areas.

As we have no historical records, then, to guide us in regard to the extinct volcanos, we must appeal to geological monuments. The annexed diagram will present to the reader, in a synoptical form, the results obtained from numerous sections.

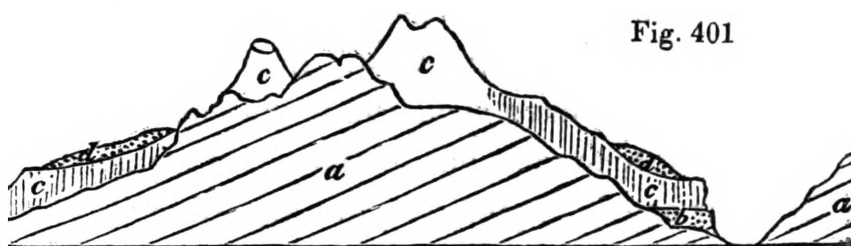


Fig. 401

Superposition of rocks in the volcanic district of Catalonia.

- a.* Sandstone and mummulitic limestone.
- b.* Older alluvium without volcanic pebbles.
- c.* Cones of scorix and lava.
- d.* Newer alluvium.

The more modern alluvium, *d*, is partial, and has been formed by the action of rivers and floods upon the lava; whereas the older gravel, *b*, was strewed over the country before the volcanic eruptions. In neither have any organic remains

been discovered ; so that we can merely affirm, as yet, that the volcanos broke out after the elevation of some of the newest rocks of the secondary series, and before the formation of an alluvium, *d*, of unknown date. The integrity of the cones merely shows that the country has not been agitated by violent earthquakes, or subjected to the action of any great transient flood since their origin.

East of Olot, on the Catalonian coast, marine tertiary strata occur, which, near Barcelona, attain the height of about five hundred feet. From the shells which I collected, these strata appear to correspond in age with the Subapennine beds ; and it is not improbable that their upheaval from beneath the sea took place during the period of volcanic eruption round Olot. In that case these eruptions may have occurred at the close of the Older Pliocene era, but perhaps subsequently, for their age is at present quite uncertain.

Miocene period—Volcanic rocks of the Eifel.—The chronological relations of the volcanic rocks of the Lower Rhine and the Eifel are also involved in a considerable degree of ambiguity ; but we know that some portion of them were coeval with the deposition of a tertiary formation, called “Brown-Coal” by the Germans, which I refer to the Miocene epoch.

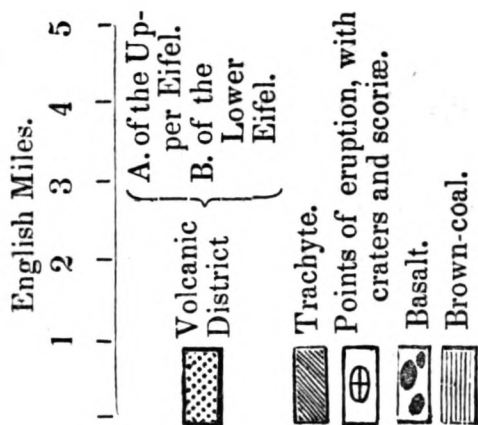
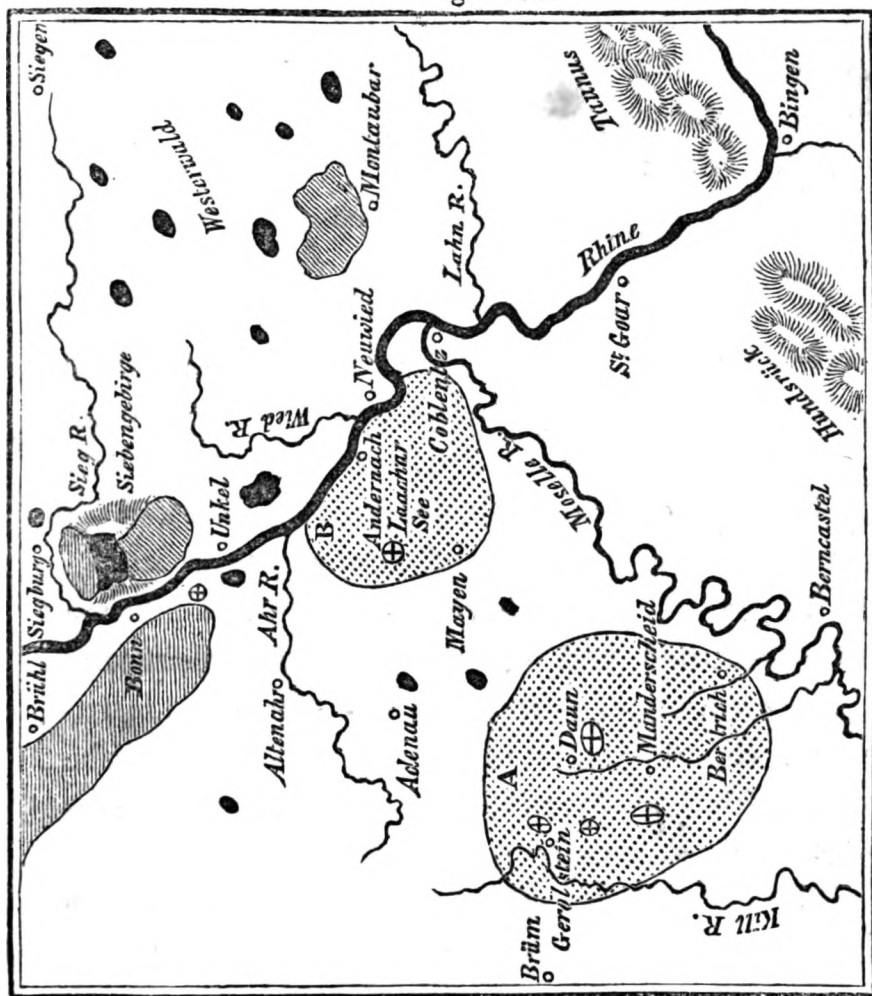


Fig. 402.



This Brown-Coal is seen on both sides of the Rhine, in the neighbourhood of Bonn, resting unconformably on highly inclined and vertical strata of Silurian and Devonian rocks. Its position, and the space occupied by the volcanic rocks, both of the Westerwald and Eifel, will be seen by referring to the annexed map (fig. 402.), for which I am indebted to Mr. Horner, whose residence in the country has enabled him to verify the maps of M. M. Noeggerath and Von Oeynhausén, from which that now given has been principally compiled.

The Brown-Coal formation consists of beds of loose sand, sandstone, and conglomerate, clay with nodules of clay ironstone, and occasionally silex. Layers of light brown and sometimes black lignite are interstratified with the clays and sands, and often irregularly diffused through them. They contain numerous impressions of leaves and stems of trees, and are extensively worked for fuel, whence the name of the formation.

In several places layers of trachytic tuff are interstratified, and in these tuffs are leaves of plants identical with those found in the brown-coal, showing that, during the period of the accumulation of the latter, some volcanic products were ejected.

The varieties of wood in the lignite are said to belong entirely to dicotyledonous trees ;

but among the impressions of leaves, collected by Mr. Horner, some were referred by Mr. Lindley to a palm, perhaps of the genus *Chamærops*, and others resembled the *Cinnamomum dulce*, and *Podocarpus macrophylla*, which would also indicate a warm climate.*

The other organic remains of the brown-coal are principally fishes ; they are found in a bituminous shale, called paper-coal, from being divisible into extremely thin leaves. The individuals are very numerous ; but they appear to belong to about five species, which M. Agassiz informs me are all extinct, and hitherto peculiar to this brown-coal. They belong to the freshwater genera *Leusiscus*, *Aspius*, and *Perca*. The remains of frogs also, of an extinct species, have been discovered in the paper-coal ; and a complete series may be seen in the museum at Bonn, from the most imperfect state of the tadpole to that of the full-grown animal. With these a salamander, scarcely distinguishable from the recent species, has been found, and several remains of insects.

The Brown-Coal was evidently a freshwater formation ; but fossil shells have been scarcely ever found in it ; although near Marienforst, in the vicinity of Bonn, large blocks have been met with of a white opaque chert, containing numer-

* Trans. of Geol. Soc., 2d ser. vol. v.

ous casts of freshwater shells, which appear to belong to *Planorbis rotundatus* and *Limnea longiscata*, two species common both to the Eocene and Miocene periods, but which have not been found in any newer deposits. It is very probable that the brown-coal may be connected in age with those fluvio-marine formations which are found in higher parts of the valley of the Rhine, as at Mayence before mentioned.

A vast deposit of gravel, chiefly composed of pebbles of white quartz, but containing also a few fragments of other rocks, lies over the Brown-Coal formation, forming sometimes only a thin covering, at others attaining a thickness of more than 100 feet. This gravel is very distinct in character from that now forming the bed of the Rhine. It is called "Kiesel gerolle" by the Germans, often reaches great elevations, and is covered in several places with volcanic ejections. It is evident that the country has undergone great changes in its physical geography since this gravel was formed; for its position has scarcely any relation to the existing drainage of the country, and all the more modern volcanic rocks of the same region are posterior to it in date.

Some of the newest beds of volcanic sand, pumice, and scorix are interstratified near Andernach and elsewhere with the loam called loess, which was before described as being full of land and freshwater shells of recent species,

and referable to the Post-pliocene period. I have before hinted (see Chap. XI.) that this intercalation of volcanic matter between beds of loess may possibly be explained without supposing the last eruptions of the Lower Eifel to have taken place so recently as the era of the deposition of the loess ; but farther researches should be directed to the investigation of this curious point.

The igneous rocks of the Westerwald, and of the mountains called the Siebengebirge, consist partly of basaltic and partly of trachytic lavas, the latter being in general the more ancient of the two. There are many varieties of trachyte, some of which are highly crystalline, resembling a coarse-grained granite, with large separate crystals of felspar. Trachytic tuff is also very abundant. These formations, some of which were certainly contemporaneous with the origin of the Brown-Coal, were the first of a long series of eruptions, the more recent of which happened when the country had acquired nearly all its present geographical features.

*Newer volcanos of the Eifel.—Lake-craters.—*As I recognized in the more modern volcanos of the Eifel characters distinct from any previously observed by me in those of France, Italy, or Spain, I shall briefly describe them. The fundamental rocks of the district are grey and red sandstones and shales, with some associated limestones, replete with fossils of the Devonian

or Old Red sandstone group. The volcanos broke out in the midst of these inclined strata, and when the present systems of hills and valleys had already been formed. The eruptions occurred sometimes at the bottom of deep valleys, sometimes on the summit of hills, and frequently on

Fig. 403.

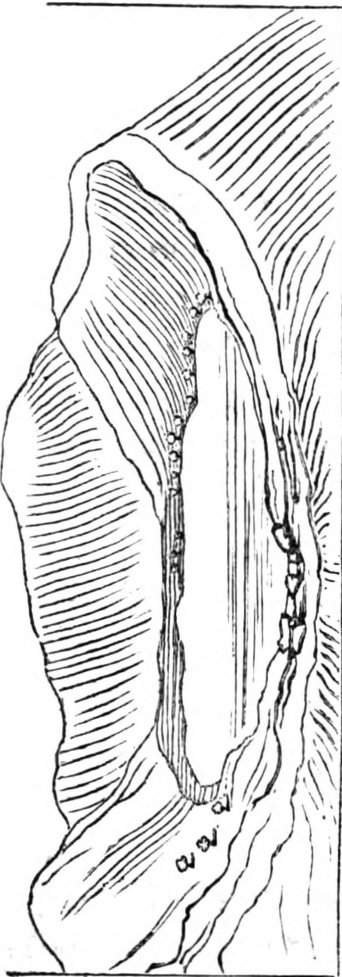
*The Gemunder Maar.*

Fig. 404.



a. Village of Gemund. *c.* Weinfelder Maar.
b. Gemunder Maar. *d.* Schalkenmehren Maar.

intervening platforms. In travelling through this district we often fall upon them most unexpectedly, and may find ourselves on the very edge of a

crater before we had been led to suspect that we were approaching the site of any igneous outburst. Thus, for example, on arriving at the village of Gemund, immediately south of Daun, we leave the stream, which flows at the bottom of a deep valley in which strata of sandstone and shale crop out. We then climb a steep hill, on the surface of which we see the edges of the same strata dipping inwards towards the mountain. When we have ascended to a considerable height, we see fragments of scoriæ sparingly scattered over the surface; till, at length, on reaching the summit, we find ourselves suddenly on the edge of a *tarn*, or deep circular lake-basin.

This, which is called the Gemunder Maar, is the first of three lakes which are in immediate contact, the same ridge forming the barrier of two neighbouring cavities (see Fig. 403.). On viewing the first of these, we recognize the ordinary form of a crater, for which we have been prepared by the occurrence of scoriæ scattered over the surface of the soil. But on examining the walls of the crater we find precipices of sandstone and shale which exhibit no signs of the action of heat; and we look in vain for those beds of lava and scoriæ, dipping in opposite directions on every side, which we have been accustomed to consider as characteristic of volcanic craters. As we proceed, however, to the opposite side of the lake, and after-

wards visit the craters *c* and *d* (Fig. 404), we find a considerable quantity of scoriæ and some lava, and see the whole surface of the soil sparkling with volcanic sand, and strewed with ejected fragments of half-fused shale, which preserves its laminated texture in the interior, while it has a vitrified or scoriform coating.

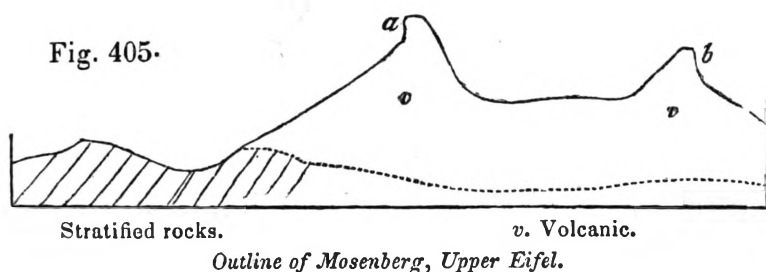
A few miles to the south of the lakes above mentioned occurs the Pulvermaar of Gillenfeld, an oval lake of very regular form, and surrounded by an unbroken ridge of fragmentary materials, consisting of ejected shale and sandstone, and preserving a uniform height of about 150 feet above the water. The side slope in the interior is at an angle of about forty-five degrees; on the exterior, of thirty-five degrees. Volcanic substances are intermixed very sparingly with the ejections, which in this place entirely conceal from view the stratified rocks of the country.*

The Meerfelder Maar is a cavity of far greater size and depth, hollowed out of similar strata; the sides presenting some abrupt sections of inclined secondary rocks, which in other places are buried under vast heaps of pulverized shale. I could discover no scoriæ amongst the ejected materials, but balls of olivine and other volcanic substances are mentioned as having been found.† This cavity,

* Scrope, Edin. Journ. of Sci., June, 1826, p. 145.

† Hibbert, Extinct Volcanos of the Rhine, p. 24.

which we must suppose to have discharged an immense volume of gas, is nearly a mile in diameter, and is said to be more than one hundred fathoms deep. In the neighbourhood is a mountain called the Mosenberg, which consists of red sandstone and shale in its lower parts, but supports on its summit a triple volcanic cone, while a distinct current of lava is seen descending the flanks of the mountain. The edge of the crater of the largest cone reminded me much of the form and characters of that of Vesuvius; but I was much struck with the precipitous and almost overhanging wall which the scoriæ presented towards the exterior, as at *a b* (Fig. 405.); which I can



only explain by supposing that fragments of red-hot lava, as they fell round the vent, were cemented together into one compact mass, in consequence of continuing to be in a half-melted state.

If we pass from the Upper to the Lower Eifel, from A to B (see map, p. 279.), we find the celebrated lake-crater of Laach, which has a greater resemblance than any of those before mentioned

to the Lago di Bolsena, and others in Italy — being surrounded by a ridge of gently sloping hills, composed of loose tuffs, scoriæ, and blocks of a variety of lavas.

One of the most interesting valcanos on the left bank of the Rhine is called the Roderberg. It forms a circular crater nearly a quarter of a mile in diameter, and one hundred feet deep, now covered with fields of corn. The highly inclined strata of ancient sandstone and shale rise even to the rim of one side of the crater; but they are overspread by quartzose gravel, and this again is covered by volcanic scoriæ and tufaceous sand. The opposite wall of the crater is composed of cinders and scorified rock, like that at the summit of Vesuvius. It is quite evident that the eruption in this case burst through the sandstone and alluvium which immediately overlies it; and I observed some of the quartz pebbles mixed with scoriæ on the flanks of the mountain, as if they had been cast up into the air, and had fallen again with the volcanic ashes. I have already observed, that a large part of this crater has been filled up with loess.*

The most striking peculiarity of a great many of the craters above described, is the absence of any signs of alteration or torrefaction in their

* See Vol. I. p. 263.

walls, when these are composed of regular strata of ancient sandstone and shale. It is evident that the summits of hills formed of the above-mentioned stratified rocks have, in some cases, been carried away by gaseous explosions, while at the same time no lava, and often a very small quantity only of scoriæ, has escaped from the newly formed cavity. There is, indeed, no feature in the Eifel volcanos more worthy of note, than the proofs they afford of very copious aëriform discharges, unaccompanied by the pouring out of melted matter, except, here and there, in very insignificant volume. I know of no other extinct volcanos where gaseous explosions of such magnitude have been attended by the emission of so small a quantity of lava. Yet I looked in vain in the Eifel for any appearances which could lend support to the hypothesis, that the sudden rushing out of such enormous volumes of gas had ever lifted up the stratified rocks immediately around the vent, so as to form conical masses, having their strata dipping outwards on all sides from a central axis, as is assumed in the theory of elevation craters, which I have fully discussed in another work.*

Trass. — In the Lower Eifel, eruptions of trachytic lava preceded the emission of currents

* See Principles of Geology.

of basalt, and immense quantities of pumice were thrown out wherever trachyte issued. The tuffaceous alluvium called *trass*, which has covered large areas in this region and choked up some valleys now partially re-excavated, is unstratified. Its base consists almost entirely of pumice, in which are included fragments of basalt and other lavas, pieces of burnt shale, slate, and sandstone, and numerous trunks and branches of trees. If this trass was formed during the period of volcanic eruptions, it may perhaps have originated in the manner of the moya of the Andes.

We may easily conceive that a similar mass might now be produced, if a copious evolution of gases should occur in one of the lake basins. The water might remain for weeks in a state of violent ebullition, until it became of the consistency of mud, just as the sea continued to be charged with red mud round Graham's Island, in the Mediterranean, in the year 1831. If a breach should then be made in the side of the cone, the flood would sweep away great heaps of ejected fragments of shale and sandstone, which would be borne down into the adjoining valleys. Forests might be torn up by such a flood; and thus the occurrence of the numerous trunks of trees dispersed irregularly through the trass, can be explained.

Hungary.—M. Beudant, in his elaborate work on Hungary, describes five distinct groups of

volcanic rocks, which, although nowhere of great extent, form striking features in the physical geography of that country, rising as they do abruptly from extensive plains composed of tertiary strata. They may have constituted islands in the ancient sea, as Santorin and Milo now do in the Grecian Archipelago ; and M. Beudant has remarked that the mineral products of the last-mentioned islands resemble remarkably those of the Hungarian extinct volcanos, where many of the same minerals, as opal calcedony, resinous silex (*silex resinite*), pearlite, obsidian, and pitchstone abound.

The Hungarian lavas are chiefly felspathic, consisting of different varieties of trachyte ; many are cellular, and used as millstones ; some so porous and even scoriform as to resemble those which have issued in the open air. Pumice occurs in great quantity ; and there are conglomerates, or rather breccias, wherein fragments of trachyte are bound together by pumiceous tuff, or sometimes by silex.

It is probable that these rocks were permeated by the waters of hot springs, impregnated, like the Geysers, with silica ; or, in some instances, perhaps, by aqueous vapours, which, like those of Lancerote, may have precipitated hydrate of silica.

By the influence of such springs or vapours

the trunks and branches of trees washed down during floods, and buried in tuffs on the flanks of the mountains, are supposed to have become silicified. It is scarcely possible, says M. Beudant, to dig into any of the pumiceous deposits of these mountains without meeting with opalized wood, and sometimes entire silicified trunks of trees of great size and weight.

It appears from the species of shells collected principally by M. Boué, and examined by M. Deshayes, that the fossil remains imbedded in the volcanic tuffs, and in strata alternating with them in Hungary, are of the Miocene type, and not identical, as was formerly supposed, with the fossils of the Paris basin.

CHAPTER XXXI.

OF THE DIFFERENT AGES OF THE VOLCANIC ROCKS —
continued.

Volcanic rocks of the Miocene period, continued—Auvergne—Mont Dor—Breccias and alluviums of Mont Perrier, with bones of quadrupeds—River dammed up by lava current—Range of minor cones from Auvergne to the Vivarais—Monts Dome—Puy de Côme—Puy de Pariou—Cones not denuded by general flood—Velay—Bones of quadrupeds buried in scoriæ—Cantal—Eocene volcanic rocks—Tuffs near Clermont—Hill of Gergovia—Trap of Cretaceous period—Oolitic period—New Red sandstone period—Carboniferous period—Old Red Sandstone period—“Rock and Spindle” near St. Andrew’s—Silurian period—Cambrian volcanic rocks.

Miocene Volcanic Rocks.—Auvergne.—THE extinct volcanos of Auvergne and Cantal in Central France seem to have commenced their eruptions in the Eocene period, but to have been most active during the Miocene era. I have already alluded to the grand succession of events, of which there is evidence in Auvergne since the last retreat of the sea (see Vol. I. p. 362.).

The earliest monuments of the tertiary period in that region are lacustrine deposits of great thickness, in the lowest conglomerates of

which are rounded pebbles of quartz, mica-schist, granite, and other non-volcanic rocks, but without the slightest intermixture of igneous products. To these conglomerates succeed argillaceous and calcareous marls containing Eocene shells, in which some feeble signs of volcanic action begin to show themselves. In the higher part of the series are freshwater marls and limestones, which alternate with volcanic tuff, and in them some fossils of the Miocene period appear. After the filling up or drainage of the ancient lakes, huge piles of trachytic and basaltic rocks, with volcanic breccias, accumulated to a thickness of several thousand feet, and were superimposed upon granite, or the contiguous lacustrine strata. The greater portion of these igneous rocks appear to have originated during the Miocene period, and extinct quadrupeds of that era, belonging to the genera *Mastodon*, *Rhinoceros*, and others, were buried in ashes and beds of alluvial sand and gravel, which owe their preservation to overspreading sheets of lava.

In Auvergne the most ancient and conspicuous of the volcanic masses is Mont Dor, which rests immediately on the granitic rocks standing apart from the freshwater strata.* This great mountain rises suddenly to the height of several thousand

* See the map, Vol. I. p. 361.

feet above the surrounding platform, and retains the shape of a flattened and somewhat irregular cone, all the sides sloping more or less rapidly, until their inclination is gradually lost in the high plain around. This cone is composed of layers of scoriæ, pumice-stones, and their fine detritus, with interposed beds of trachyte and basalt, which descend often in uninterrupted sheets, till they reach and spread themselves round the base of the mountain.* Conglomerates, also, composed of angular and rounded fragments of igneous rocks, are observed to alternate with the above ; and the various masses are seen to dip off from the central axis, and to lie parallel to the sloping flanks of the mountain.

The summit of Mont Dor terminates in seven or eight rocky peaks, where no regular crater can now be traced, but where we may easily imagine one to have existed, which may have been shattered by earthquakes, and have suffered degradation by aqueous agents. Originally, perhaps, like the highest crater of Etna, it may have formed an insignificant feature in the great pile, and may frequently have been destroyed and renovated.

According to some geologists, this mountain, as well as Vesuvius, Etna, and all large volcanos, has derived its dome-like form not from the

* Scrope's Central France, p. 98.

preponderance of eruptions from one or more central points, but from the upheaval of horizontal beds of lava and scoriæ. I have explained my reasons for objecting to this view in the *Principles of Geology*. Nevertheless we may expect to find that during the long series of eruptions required to give rise to so vast a pile of volcanic matter, much dislocation and upheaval took place ; and during the distention of the mass some beds of lava and scoriæ may have acquired a greater, others a less, inclination, than that which at first belonged to them.*

Respecting the age of the great mass of Mont Dor, we cannot come at present to any positive decision, because no organic remains have yet been found in the tuffs, except impressions of the leaves of trees of species not yet determined. We may certainly conclude, that the earliest eruptions were posterior in origin to those grits and conglomerates of the freshwater formation of the Limagne which contain no pebbles of volcanic rocks. But it will be shewn that some eruptions took place before the great lakes were drained ; while others occurred after the desiccation of those lakes, and when deep valleys had already been excavated through freshwater strata. Even some trachytic breccias, such as those of

* See *Principles*, particularly 6th ed., vol. ii. chap. 13.

Mont Perrier, for example, which precisely resemble others in Mont Dor, and doubtless descended from it, are found on the flanks of a valley which was first hollowed out of the Eocene strata, then filled with breccia and alluvium, and afterwards, to a great extent, re-excavated. The annexed drawing will explain the position of the breccias *b* and *d* above alluded to, and of two associated beds of ancient alluvium, *c* and *e*, in which the remains of quadrupeds

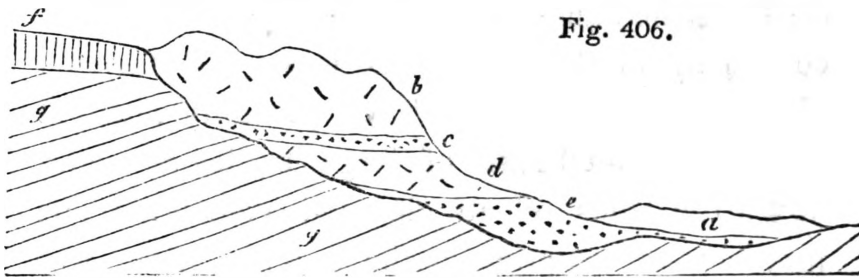


Fig. 406.

Position of the Volcanic breccias and alluviums of Mont Perrier, Auvergne.

Descending series.

- | | |
|---|-------------------------------------|
| <i>a.</i> Newer alluvium. | <i>b.</i> Second trachytic breccia. |
| <i>c.</i> Second Miocene alluvium with bones. | |
| <i>d.</i> First trachytic breccia. | |
| <i>e.</i> First Miocene alluvium with bones. | |
| <i>f.</i> Compact basalt. | <i>g.</i> Eocene lacustrine strata. |

characteristic of the Miocene period have been obtained. In order to account for the situation of these masses, we must suppose that after the tertiary strata *g*, covered by the basaltic lava *f*, had been exposed to aqueous denudation, the alluvium *e* had accumulated in a valley. The remains of quadrupeds then inhabiting the

country, and which had been drowned, perhaps, during floods, were buried in silt, gravel, and sand *e*. The trachytic breccia *d* was then superimposed ; this breccia is an aggregate of shapeless and angular fragments of trachyte, cemented by volcanic tuff and pumice, precisely resembling some of the breccias which enter into the composition of the neighbouring Mont Dor, and which are very analogous to some found on Etna. Upon this rests another alluvium, *c*, which also contains the bones of Miocene species, and this is covered by another enormous mass of tufaceous breccia. The breccias have probably resulted from the sudden rush of large bodies of water down the sides of an elevated volcano at its moments of eruption, perhaps when snow was melted by lava. Such floods occur in Iceland, sweeping away loose blocks of lava and ejections surrounding the crater, and then strewing the plains with fragments of igneous rocks, enveloped in mud or “moya.” The abrupt escarpment presented by the above-described beds, *b*, *c*, *d*, *e*, towards the valley of the Couze, must have been caused by subsequent erosion, which has carried away a large portion of those masses.*

* For an account of the position and age of the volcanic breccias of Mont Perrier and Boulade, see Lyell and Murchison on the Beds of Mont Perrier, Ed. New Phil. Journ., July, 1829, p. 15.

The newest alluvium (*a*) may also serve to represent the position occupied farther up the same valley by the most modern lava stream of the Puy de Tartaret, by connecting which with the section now under consideration, we have before us the signs of a remarkable succession of volcanic operations. The first of these produced the ancient columnar basalt (*f*); the second, the trachytic breccia (*d*); the third, the breccia (*b*); and the fourth, the most modern lava (*a*); which last, although comparatively modern, may still, as we shall afterwards see, be of indefinite antiquity.

In the alluviums *c* and *e*, MM. Croizet, Jobert, Chabriol, and Bouillet have discovered the remains of about forty species of extinct mammalia, the greater part of which are peculiar as yet to this locality; but some of them are characteristic of the Miocene period, being common to the faluns of Touraine, and associated in other localities with marine Miocene strata. Among these species may be enumerated *Mastodon minor* and *M. arvernensis*, *Hippopotamus major*, *Rhinoceros leptorhinus*, and *Tapir arvernensis*. The *Elephas primigenius*, a species common to so many tertiary periods, is also stated to accompany the rest. In some cases the remains are not sufficiently characteristic to indicate the exact species, but the following genera can be determined:—

The boar, horse, ox, hyæna (two species), felis (three or four), bear (three), deer (many species), canis, otter, beaver, hare, and water-rat.*

The great mass of Mont Dor must have resulted from a long series of eruptions, by which melted matter was poured forth again and again from one vent, or from several neighbouring orifices. But here, as on Etna, there were numerous minor cones, which were thrown up in the valleys and ravines formed by earthquakes and floods in the course of ages, on the flanks, and at the base of the great volcano. Thus in the valley of Chambon, the boundary precipices of which are formed by ancient columnar trachytes and basalts, the Puy de Tartaret has been cast up, so as to obstruct and dam up the channel of the river Couze with its cone of loose scorïæ and its lava-current, which has flowed down the valley for thirteen miles. The barrier thus thrown across the ancient course of the stream gave rise to a lake which exists to this day ; but although the river has been unable to cut out a new channel of sufficient depth to drain this lake, it has at several points below its outlet, eaten into the lava to such a depth as to lay open a bed of river gravel which existed before

* Recherches sur les Oss. Foss. du Dépt. du Puy de Dome, 4to. 1828. Essai Géol. et Minéral. sur les Environs d'Issoire, Dépt. du Puy de Dome, folio, 1827.

the lava of Tartaret, now incumbent upon it, was poured out, in the same manner as was explained in sections, Fig. 400. p. 274. and Vol. I. p. 167.

In Central France there are several hundred minor cones, like that of Tartaret, a great number of which, like Monte Nuovo, near Naples, may have been principally due to a single eruption. Most of these cones range in a linear direction from Auvergne to the Vivarais, and they were faithfully described so early as the year 1802, by M. de Montlosier. They have given rise chiefly to currents of basaltic lava. Those of Auvergne called the *Monts Dome*, placed on a granitic platform, form an irregular ridge (see Fig. 369.), about eighteen miles in length and two in breadth. They are usually truncated at the summit, where the crater is often preserved entire, the lava having issued from the base of the hill. But frequently the crater is broken down on one side, where the lava has flowed out. The hills are composed of loose *scoriæ*, blocks of lava, *lapilli*, and *pozzuolana*, with fragments of trachyte and granite.

The lavas, like that of Tartaret already mentioned, may be often traced from the crater to the nearest valley, where they usurp the channel of the river, which has frequently excavated a deep ravine through the basalt. We have thus an opportunity of contrasting the enormous de-

gradation which the solid and massive rock has suffered by aqueous erosion, and the integrity of the cone of sand and ashes which has, in the mean time, remained uninjured on the neighbouring platform, where it was placed beyond the reach of the power of running water. Had any great diluvial rush of waters expended its fury on the more elevated parts of this district, such cones must have been greatly modified in form, if not entirely swept away.

Puy de Côme. — The Puy de Côme and its lava current, near Clermont, may be mentioned as one of the numerous illustrations of the phenomenon here alluded to. This conical hill rises from the granitic platform, at an angle of about 40° , to the height of more than 900 feet. Its summit presents two distinct craters, one of them with a vertical depth of 250 feet. A stream of lava takes its rise at the western base of the hill, instead of issuing from either crater, and descends the granitic slope towards the present site of the town of Pont Gibaud. Thence it pours in a broad sheet down a steep declivity into the valley of the Sioule, filling the ancient river-channel for the distance of more than a mile. The Sioule, thus dispossessed of its bed, has worked out a fresh one between the lava and the granite of its western bank ; and the exca-

vation has disclosed, in one spot, a wall of columnar basalt about 50 feet high.*

The excavation of the ravine is still in progress, every winter some columns of basalt being undermined and carried down the channel of the river, and in the course of a few miles rolled to sand and pebbles. Meanwhile the cone of Côme remains stationary, its loose materials being protected by a dense vegetation, and the hill standing on a ridge not commanded by any higher ground whence floods of rain-water may descend.

Puy Rouge.—At another point, farther down the course of the Sioule, we find a second illustration of the same phenomenon in the Puy Rouge, a conical hill to the north of the village of Pranal. The cone is composed entirely of red and black scoriæ, tuff, and volcanic bombs. On its western side there is a worn-down crater, whence a powerful stream of lava has issued, and flowed into the valley of the Sioule. The river has since excavated a ravine through the lava and subjacent gneiss, to the depth of 400 feet.

On the upper part of the precipice forming the left side of this ravine, we see a great mass of black and red scoriaceous lava; below this a thin bed of gravel, evidently an ancient river-bed, now at an elevation of fifty feet above the channel

* Scrope's Central France, p. 60., and plate.

of the Sioule. The gravel again rests upon gneiss, which has been eroded to the depth of 50 feet. It is quite evident in this case, that, while the basalt was gradually undermined and carried away by the force of running water, the cone whence the lava issued escaped destruction, because it stood upon a platform of gneiss several hundred feet above the level of the valley in which the force of running water was exerted.

Puy de Pariou.—The brim of the crater of the Puy de Pariou, near Clermont, is so sharp, and has been so little blunted by time, that it scarcely affords room to stand upon. This and other cones in an equally remarkable state of integrity have stood, I conceive uninjured, not *in spite* of their loose porous nature, as might at first be naturally supposed, but in consequence of it. No rills can collect where all the rain is instantly absorbed by the sand and scoriæ, as is remarkably the case on Etna ; and nothing but a water-spout breaking directly upon the Puy de Pariou could carry away a portion of the hill, so long as it is not rent or engulfed by earthquakes.

Hence it is conceivable that even those cones which have the freshest aspect, and most perfect shape, may lay claim to an indefinite antiquity. Dr. Daubeny has justly observed, that had any of these volcanos been in a state of activity in the age of Julius Cæsar, that general, who encamped

upon the plains of Auvergne, and laid seige to its principal city (Gergovia, near Clermont), could hardly have failed to notice them. Had there been any record of their eruptions in the time of Pliny or Sidonius Apollinaris, the one would scarcely have omitted to make mention of it in his *Natural History*, nor the other to introduce some allusion to it among the descriptions of this his native province. This poet's residence was on the borders of the Lake Aidat, which owed its very existence to the damming up of a river by one of the most modern lava-currents.*

The ruins of several Roman bridges, and of the Roman baths at Royat, confirm the conclusion that no sensible alteration has taken place in the physical geography of the district, not even in the chasms excavated through the newest lavas since ages historically remote. We have no data at present for presuming that any one of the Auvergene cones has been produced within the last four or five thousand years; and the same may be said of those of Velay; and, until the bones of men or articles of human workmanship are found buried under some of their lavas, instead of the remains of extinct animals, which alone have hitherto been met with, we are justified in regarding it as probable that the latest of

* Daubeny on Volcanos, p. 14.

of the volcanic eruptions may have occurred during the Miocene period.

Velay.—The observations of M. Bertrand de Doue have not yet established that any of the most ancient volcanos of Velay were in action during the Eocene period. There are beds of gravel in Velay as in Auvergne, covered by lava at different heights above the channels of the existing rivers. In the highest and most ancient of these alluviums the pebbles are exclusively of granitic rocks; but in the newer, which are found at lower levels, and which originated when the valleys had been cut to a greater depth, an intermixture of volcanic rocks has been observed.

At St. Privat d'Allier a bed of volcanic scorix and tuff was discovered by Dr. Hibbert, inclosed between two sheets of basaltic lava; and in this tuff were found the bones of several quadrupeds, some of them adhering to masses of slaggy lava. Among other animals were *Rhinoceros leptorhinus*, *Hyæna spelæa*, and a species allied to the spotted hyæna of the Cape, together with four undetermined species of deer.* The manner of the occurrence of these bones reminds us of the recently published accounts of an eruption of

* Edin. Journ. of Sci., No. iv. N. S. p. 276. Figures of some of these remains are given by M. Bertrand de Doue, Ann. de la Soc. d'Agricult. de Puy, 1828.

Coseguina, 1835, in central America (see p.244.), during which hot cinders and scoriæ fell and scorched to death great numbers of wild and domestic animals and birds.

Plomb du Cantal.—In regard to the age of the igneous rocks of the Cantal, we can at present merely affirm, that they overlie the Eocene lacustrine strata of that country (see Map Vol. I. p. 361.). They form a great dome-shaped mass, which has evidently been accumulated, like the cone of Etna, during a long series of eruptions. It is composed of trachytic, phonolitic, and basaltic lavas, tuffs, and conglomerates, or breccias, forming a mountain several thousand feet in height. Dikes also of phonolite, trachyte, and basalt are numerous, especially in the neighbourhood of the large cavity, probably once a crater, around which the loftiest summits of the Cantal are ranged circularly, few of them, except the Plomb du Cantal, rising far above the border or ridge of this supposed crater. A pyramidal hill, called the Puy Griou, occupies the middle of the cavity.* It is evident that the volcano of the Cantal broke out precisely on the site of the lacustrine deposit before described (Chap. XVI.), which had accumulated in a depression of a tract composed of micaceous schist. In the breccias,

* Mém. de la Soc. Géol. de France, tom i. p. 175.

even to the very summit of the mountain, we find ejected masses of the freshwater beds, and sometimes fragments of flint, containing Eocene shells. Valleys radiate in all directions from the central heights of the mountain, increasing in size as they recede from those heights. Those of the Cer and Jourdanne, which are more than twenty miles in length, are of great depth, and lay open the geological structure of the mountain. No alternation of lavas with undisturbed Eocene strata has been observed, nor any tuffs containing fresh water shells, although some of these tuffs include fossil remains of terrestrial plants, said to imply several distinct restorations of the vegetation of the mountain in the intervals between great eruptions. On the northern side of the Plomb du Cantal, at La Vissiere, near Murat, is a spot, pointed out on the Map (Vol. I. p. 361.), where freshwater limestone and marl are seen covered by a thickness of about eight hundred feet of volcanic rock. Shifts are here seen in the strata of limestone and marl.*

Eocene period. — In treating of the lacustrine deposits of Central France, in the sixteenth chapter, it was stated that, in the arenaceous and pebbly group of the lacustrine basins of Auvergne, Cantal, and Velay, no volcanic pebbles had ever been detected, although massive piles of igneous

* See Lyell and Murchison, Ann. des Sci. Nat., Oct. 1829.

rocks are now found in the immediate vicinity. As this observation has been confirmed by minute research, we are warranted in inferring that the volcanic eruptions had not commenced when the older subdivisions of the freshwater groups originated.

In Cantal and Velay no decisive proofs have yet been brought to light that any of the igneous outburst happened during the deposition of the freshwater strata ; but there can be no doubt that in Auvergne some volcanic explosions took place before the drainage of the lakes, and at a time when the Eocene species of animals and plants still flourished. Thus, for example, at Pont du Château, near Clermont, a section is seen in a precipice on the right bank of the river Allier, in which beds of volcanic tuff alternate with a freshwater limestone, which is in some places pure, but in others spotted with fragments of volcanic matter, as if it were deposited while showers of sand and scorix were projected from a neighbouring vent.* This limestone contains *Helix Ramondi* and other shells of Eocene species. In reference to the chronological question, it is immaterial whether the volcanic sand was showered down from above, or drifted to the spot by a river ; for the latter opinion must presuppose the country

* See Scrope's Central France, p. 21.

to have been covered with volcanic ejections during the Eocene period.

Another example occurs in the Puy de Mar-mont, near Veyres, where a freshwater marl alternates with volcanic tuff containing Eocene shells. The tuff or breccia in this locality is precisely such as is known to result from volcanic ashes falling into water, and subsiding together with ejected fragments of marl and other stratified rocks. These tuffs and marls are highly inclined, and traversed by a thick vein of basalt, which, as it rises in the hill, divides into two branches.

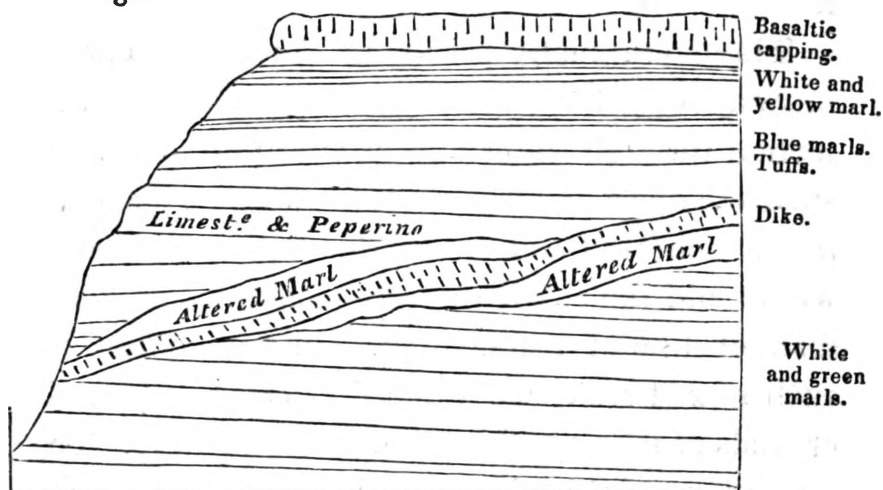
Gergovia.—The hill of Gergovia, near Clermont, affords a third example. I agree with MM. Dufrénoy and Jobert that there is no alternation here of a contemporaneous sheet of lava with freshwater strata, in the manner supposed by some other observers* ; but the position and contents of some of the associated tuffs, prove them to have been derived from volcanic eruptions which occurred during the deposition of the lacustrine strata.

The bottom of the hill consists of slightly inclined beds of white and greenish marls, more than three hundred feet in thickness, intersected by a dike of basalt, which may be studied in the ravine

* See Scrope's Central France, p. 7.

above the village of Merdogne. The dike here cuts through the marly strata at a considerable angle, producing, in general, great alteration and

Fig. 407.



Hill of Gergovia.

confusion in them for some distance from the point of contact. Above the white and green marls, a series of beds of limestone and marl, containing freshwater shells, are seen to alternate with volcanic tuff. In the lowest part of this division, beds of pure marl alternate with compact fissile tuff, resembling some of the subaqueous tuffs of Italy and Sicily called *peperinos*. Occasionally fragments of scoriæ are visible in this rock. Still higher is seen another group of some thickness, consisting exclusively of tuff, upon which lie other marly strata intermixed with volcanic matter. An account of the precise species of fossils found in these strata would be highly

interesting, and enable us to decide whether the upper part of the great freshwater series does not indicate a passage from an Eocene to a Miocene fauna.

There are many points in Auvergne where igneous rocks have been forced by subsequent injection through clays and marly limestones, in such a manner that the whole has become blended in one confused and brecciated mass, between which and the basalt there is sometimes no very distinct line of demarcation. In the cavities of such mixed rocks we often find calcedony, and crystals of mesotype, stilbite, and arragonite. To formations of this class may belong some of the breccias immediately adjoining the dike in the hill of Gergovia ; but it cannot be contended that the volcanic sand and scorïæ interstratified with the marls and limestones in the upper part of that hill were introduced, like the dike, subsequently, by intrusion from below. They must have been thrown down like sediment from water, and can only have resulted from igneous action, which was going on contemporaneously with the deposition of the lacustrine strata.

The reader will bear in mind that this conclusion agrees well with the proofs, adverted to in the sixteenth chapter, of the abundance of silex, travertin, and gypsum precipitated when the upper lacustrine strata were formed ; for these

rocks are such as the waters of mineral and thermal springs might generate.

Cretaceous period. — Although we have no proof of volcanic rocks erupted in England during the deposition of the chalk and green-sand, it would be an error to suppose that no theatres of igneous action existed in the cretaceous period. M. Virlet, in his account of the geology of the Morea (p. 205.), has clearly shown that certain traps in Greece, called by him ophiolites, are of this date ; as those, for example, which alternate conformably with cretaceous limestone and green-sand between Kastri and Damala in the Morea. They consist in great part of diallage rocks and serpentine, and of an amygdaloid with calcareous kernels, and a base of serpentine.

In certain parts of the Morea, the age of these volcanic rocks is established by the following proofs : first, the lithographic limestones (see Vol. I. p. 413.) of the Cretaceous era are cut through by trap, and then a conglomerate occurs, at Nauplia and other places, containing in its calcareous cement many well-known fossils of the chalk and green-sand, together with pebbles formed of rolled pieces of the same ophiolite, which appear in the dikes above alluded to.

It was before stated that strata occur at Tercis, near Dax, in the department of the Landes, in the south of France, containing the fossils of the

Chalk. These cretaceous strata are in great part concealed by unconformable tertiary formations. In one section in this district I observed vertical cretaceous beds, alternating with thin conform-

Fig. 408. Adour R. Luy R. Puy Arzet.



Chalk and volcanic tuff in the environs of Dax.

- E. Inclined beds of Chalk and conformable volcanic tuff.
 a. b. c. d. Gravel, sand, and tertiary strata.

able layers of volcanic tuff. Such tuffs were probably the product of submarine eruptions in the cretaceous sea.

The traps of this country and of the neighbouring Pyrenees are generally ophitic, and many French geologists conceive them to be newer than the Cretaceous period, and therefore tertiary; but I know of no sections which demonstrate this point. M. Charpentier has argued that the ophites of the Pyrenees were more modern than all the secondary strata of that chain, because in the conglomerates constituting the upper part of the cretaceous series on the flanks of the Pyrenees, no rolled pebbles of ophite have been found.* But this negative fact may be explained by supposing that, in the cretaceous sea, which occupied

* Charpentier, *Essai Geog. sur les Pyrénées*, p. 524.

the space where the Pyrenees now stand, the ophitic eruptions were submarine, and never formed islands or shoals exposed to denudation.

The age of the trap of Antrim in Ireland, before described, as altering the chalk by its dikes (p. 220.), is uncertain. It is newer than the chalk of that region, which it cuts through and overflows; and, perhaps, it belongs to some one of the tertiary periods. As wood-coal and coniferous fossil trees have been found associated with it on the eastern shores of Lough Neagh, these plants may hereafter throw light on this chronological question.*

Period of Oolite and Lias. — Although the green and serpentinous trap rocks of the Morea belong chiefly to the Cretaceous era, as before mentioned, yet it seems that some eruptions of similar rocks began during the Oolitic period†; and it is probable, that a large part of the trap-pean masses, called ophiolites in the Apennines, and associated with the limestone of that chain, are of corresponding age.

Whether part of the volcanic rocks of the Hebrides, in our own country, originated contemporaneously with the Lias and Oolite which they traverse and overlie, remains to be ascertained.

* Dr. Berger, Geol. Trans., First Series, vol. iii. p. 188.

† Boblaye and Virlet, Morea, p. 23.

Trap of the New Red sandstone period.—In the southern part of Devonshire, trappean rocks are associated with New Red sandstone, and according to Mr. De la Beche, have not been intruded subsequently into the sandstone, but were produced by contemporaneous volcanic action. Some beds of grit, mingled with ordinary red marl, resemble sands ejected from a crater; and in the stratified conglomerates occurring near Tiverton are many angular fragments of trap porphyry, some of them one or two tons in weight, intermingled with pebbles of other rocks. These angular fragments were probably thrown out from volcanic vents, and fell upon sedimentary matter then in the course of deposition.*

Carboniferous period.—Two classes of contemporaneous trap rocks have been ascertained by Dr. Fleming to occur in the coal-field of the Forth in Scotland. The newest of these, connected with the higher series of coal-measures, is well exhibited along the shores of the Forth, in Fifeshire, where they consist of basalt with olivine, amygdaloid, greenstone, wacké, and tuff. They appear to have been erupted while the sedimentary strata were in a horizontal position, and to have suffered the same dislocations which those strata have subsequently undergone. In the vol-

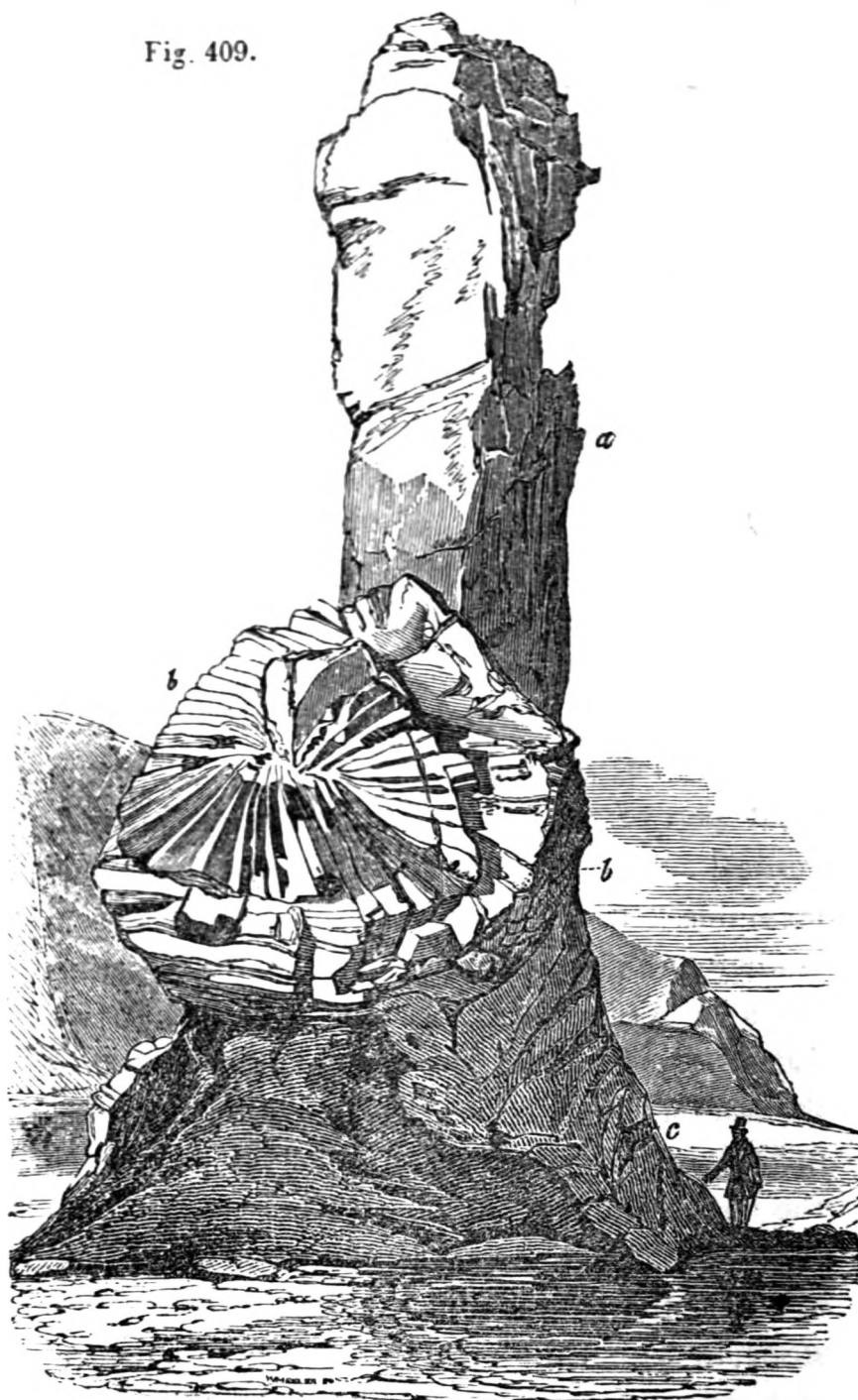
* De la Beche, Geol. Proceedings, No. 41. p. 196.

canic tuffs of this age are found not only fragments of limestone, shale, flinty slate, and sandstone, but also pieces of coal.

The other or older class of carboniferous traps are traced along the south margin of Stratheden, and constitute a ridge parallel with the Ochils, and extending from Stirling to near St. Andrews. They consist almost exclusively of greenstone, becoming, in a few instances, earthy and amygdaloidal. They are regularly interstratified with the sandstone, shale, and ironstone of the lower Coal-measures, and, on the East Lomond, with Mountain Limestone.

I examined these trap rocks in 1838, in the cliffs south of St. Andrews where they consist in great part of stratified tuffs, which are curved, vertical and contorted, like the associated coal-measures. In the tuff I found fragments of carboniferous shale and limestone, and intersecting veins of greenstone. At one spot, about two miles from St. Andrews, the encroachment of the sea on the cliffs has isolated several masses of trap, one of which (Fig. 409.) is aptly called the "rock and spindle," for it consists of a pinnacle of tuff, which may be compared to a distaff, and near the base is a mass of columnar greenstone, in which the pillars radiate from a centre, and appear at a distance like the spokes of a wheel. The largest diameter of this wheel is

Fig. 409.



Rock and Spindle, St. Andrews.

a Unstratified tuff.

b. Columnar greenstone.

c. Stratified tuff.

about twelve feet, and the polygonal terminations of the columns are seen round the circum-

Fig. 410.



ference (or tire, as it were, of the wheel), as in the accompanying figure. I conceive this mass to be the extremity of a string or vein of greenstone, which penetrated the tuff. The prisms point

in every direction, because they were surrounded on all sides by cooling surfaces, to which they always arrange themselves at right angles, as before explained, p. 228.

A trap dike was pointed out to me by Dr. Fleming, in the parish of Flisk, in the northern part of Fifeshire, which cuts through the grey sandstone and shale, forming the lowest part of the Old Red Sandstone. It may be traced for many miles, passing through the amygdaloidal and other traps of the hill called Normans Law. In its course it affords a good exemplification of the passage from the trappean into the plutonic, or highly crystalline texture. Professor Gustavus Rose, to whom I submitted specimens of this dike, finds the rock which he calls dolerite, to consist of greenish black augite and Labrador felspar, the latter being the most abundant ingredient. A small quantity of magnetic iron, perhaps titaniferous, is also present. The result of this analysis is interesting, because

both the ancient and modern lavas of Etna consist in like manner of augite, Labradorite, and titaniferous iron.

Trap of the Old Red sandstone period. — By referring to the section explanatory of the structure of Forfarshire, already given (Vol. I. p. 103.), the reader will perceive that beds of conglomerate, No. 3., occur in the middle of the Old Red sandstone system, 1, 2, 3, 4. The pebbles in these conglomerates are sometimes composed of granitic and quartz rocks, sometimes exclusively of different varieties of trap, which, although purposely omitted in the above section, are often found, either intruding themselves in amorphous masses and dikes into the older fossiliferous tilestones, No. 4., or alternating with them in conformable beds. All the different divisions of the red sandstone, 1, 2, 3, 4, are occasionally intersected by dikes, but they are very rare in Nos. 1. and 2., the upper members of the group consisting of red shale and red sandstone. These phenomena, which occur at the foot of the Grampians, are repeated in the Sidlaw Hills; and it appears that in this part of Scotland volcanic eruptions were most frequent in the earlier part of the Old Red sandstone period.

The trap rocks alluded to consist chiefly of feldspathic porphyry and amygdaloid, the kernels of the latter being sometimes calcareous, often calcedonic, and forming beautiful agates. We

meet also with claystone, clinkstone, greenstone, compact felspar, and tuff. Some of these rocks flowed as lavas over the bottom of the sea, and enveloped quartz pebbles which were lying there, so as to form conglomerates with a base of greenstone, as is seen in Lumley Den, in the Sidlaw Hills. On either side of the axis of this chain of hills (see section, Vol. I. p. 103.), the beds of massive trap, and the tuffs composed of volcanic sand and ashes, dip regularly to the south-east or north-west, conformably with the shales and sandstones.

Dr. Fleming has observed similar trap rocks in the old red sandstone of northern Fifeshire, where they are covered immediately by the yellow sandstone which occurs at the base of the Mountain Limestone and Coal-measures, and may be considered as the upper member of the Old Red system.

Silurian period.—It appears from the investigations of Mr. Murchison in Shropshire, that when the lower Silurian strata of that country were accumulating, there were frequent volcanic eruptions beneath the sea; and the ashes and scorix then ejected gave rise to a peculiar kind of tufaceous sandstone or grit, dissimilar to the other rocks of the Silurian series, and only observable in places where syenitic and other trap rocks protrude. These tuffs occur on the flanks

of the Wrekin and Caer Caradoc, and contain Silurian fossils, such as casts of encrinurites, trilobites, and mollusca. Although fossiliferous, the stone resembles a sandy claystone of the trap family.*

Thin layers of trap, only a few inches thick, alternate, in some parts of Shropshire and Montgomeryshire, with sedimentary strata of the lower Silurian system. This trap consists of slaty porphyry and granular felspar rock, the beds being traversed by joints like those in the associated sandstone, limestone, and shale, and having the same strike and dip.†

In Radnorshire, there is an example of twelve bands of stratified trap alternating with Silurian schists and flagstones in a thickness of 350 feet. The bedded traps consist of felspar-porphry, clinkstone, and other varieties; and the interposed Llandeilo flags are of sandstone and shale, with trilobites and graptolites.‡

Cambrian volcanic rocks.—In Pembrokeshire stratified greenstone, felspar-rock, and a breccia containing fragments of trap, alternate conformably in thick parallel masses with regularly stratified sandstone and schist of the *upper Cambrian* system. These trappean masses, says Mr. Murchison, must have been evolved at intervals from volcanic fissures at the bottom of the sea, when

* Murchison, *Silurian System*, &c., p. 230.

† Ibid., p. 272.

‡ Ibid., p. 325.

the sand, pebbles, and mud, now forming the accompanying sedimentary rocks, were deposited.*

Professor Sedgwick, in his account of the geology of Cumberland, has described various trap-rocks which accompany the green slates of the Cambrian system, beneath a limestone containing organic remains. Different felspathic and porphyritic rocks and greenstones occur, not only in dikes, but in conformable beds; and there is occasionally a passage from these igneous rocks to some of the green quartzose slates. Professor Sedgwick supposes these porphyries to have originated contemporaneously with the stratified chloritic slates, the materials of the slates having been supplied, in part at least, by submarine eruptions oftentimes repeated.†

* Murchison, *Silurian System*, &c., p. 404.

† *Geol. Trans., Second Series*, vol. iv. p. 55.

CHAPTER XXXII.

PLUTONIC ROCKS—GRANITE.

General aspect of granite—Decomposing into spherical masses—Rude columnar structure—Analogy and difference of volcanic and plutonic formations—Minerals in granite, and their arrangement—Graphic and porphyritic granite—Occasional minerals—Syenite—Syenitic, talcose, and schorly granites—Eurite—Passage of granite into trap—Examples near Christiania and in Aberdeenshire—Analogy in composition of trachyte and granite—Granite veins in Glen Tilt, Cornwall, the Valorsine, and other countries—Different composition of veins from main body of granite—Metalliferous veins in strata near their junction with granite—Apparent isolation of nodules of granite—Quartz veins—Whether plutonic rocks are ever overlying—Their exposure at the surface due to denudation.

THE plutonic rocks may be treated of next in order, as they are most nearly allied to the volcanic class already considered. I have described, in the first chapter, these plutonic rocks as the unstratified division of the crystalline or hypogene formations, and have endeavoured to point out in the Frontispiece, at D, the position which they may occupy, when first formed, relatively to the volcanic formations, B.

It was stated that they differ from the latter, not only by their more crystalline texture, but also by

the absence of tuffs and breccias, which are the products of eruptions at the earth's surface, or beneath seas of inconsiderable depth. They differ also by the absence of pores or cellular cavities to which the expansion of the entangled gases give rise in ordinary lava. From these and other peculiarities it has been inferred, that the granites have been formed at great depths in the earth, and have cooled and crystallized slowly under enormous pressure where the contained gases could not expand. The volcanic rocks, on the contrary, although they also have risen up from below, have cooled from a melted state more rapidly upon or near the surface. From this hypothesis of the great depth at which the granites originated, has been derived the name of "Plutonic rocks." The beginner will easily conceive that the influence of subterranean heat may extend downwards from the crater of every active volcano to a great depth below, perhaps several miles or leagues (see Frontispiece), and the effects which are produced deep in the bowels of the earth may, or rather must be distinct ; so that volcanic and plutonic rocks, each different in texture, and sometimes even in composition, may originate simultaneously, the one at the surface, the other far beneath it.

By some writers, all the rocks now under consideration have been comprehended under the name of granite, which is, then, understood to em-

brace a large family of crystalline and compound rocks, usually found underlying all other formations ; whereas we have seen that trap very commonly overlies strata of different ages. Granite often preserves a very uniform character throughout a wide range of territory, forming hills of a peculiar rounded form, usually clad with a scanty vegetation. The surface of the rock is for the most part in a crumbling state, and the hills are often surmounted by piles of stones like the remains of a stratified mass, as in the annexed figure, and sometimes like heaps of boulders, for

Fig. 411.

*Mass of granite near the Sharp Tor, Cornwall.*

which they have been mistaken. The exterior of these stones, originally quadrangular, acquires a rounded form by the action of air and water, for the edges and angles waste away more rapidly than the sides. A similar spherical structure has already been described as characteristic of basalt, and other volcanic formations, and it must be referred to analogous causes, as yet but imperfectly understood.

Although it is the general peculiarity of granite to assume no definite shapes, it is nevertheless occasionally subdivided by fissures, so as to assume a cuboidal, and even a columnar, structure. Examples of these appearances may be seen near the Land's End, in Cornwall. (See figure.)

Fig. 412.



*Granite having a cuboidal and rude columnar structure.
Land's End, Cornwall.*

The plutonic formations also agree with the volcanic, in having veins or ramifications proceeding from central masses into the adjoining rocks, and causing alterations in these last, which will be presently described. They also resemble trap in

containing no organic remains ; but they differ in being more uniform in texture, whole mountain masses of indefinite extent appearing to have originated under conditions precisely similar. But they differ in never being scoriaceous or amygdaloidal, in never forming a porphyry with an uncrystalline base, and never alternating with tuffs. Nor do they form conglomerates, although there is sometimes an insensible passage from a fine to a coarse-grained granite, and occasionally patches of a fine texture are imbedded in a coarser variety.

Felspar, quartz, and mica are usually considered as the minerals essential to granite, the felspar being most abundant in quantity, and the proportion of quartz exceeding that of mica. These minerals are united in what is termed a confused crystallization ; that is to say, there is no regular arrangement of the crystals in granite, as in gneiss (see Fig. 413.), except in the variety

Fig. 413.



Gneiss. (See description, p. 380.)

termed graphic granite, which occurs mostly in

granitic veins. This variety is a compound of felspar and quartz, so arranged as to produce an imperfect laminar structure. The crystals of fel-

Fig. 414.

Fig. 415.

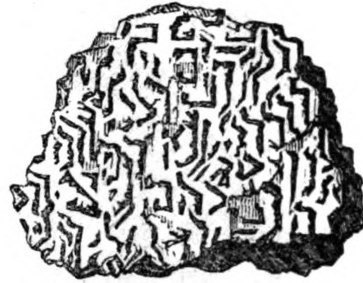
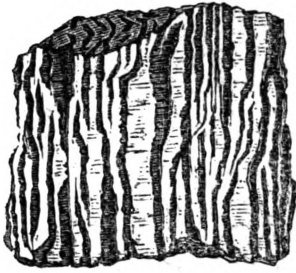
*Graphic granite.*

Fig. 414. Section parallel to the laminæ.

Fig. 415. Section transverse to the laminæ.

spar appear to have been first formed, leaving between them the space now occupied by the darker-coloured quartz. This mineral, when a section is made at right angles to the alternate plates of felspar and quartz, presents broken lines, which have been compared to Hebrew characters.

Porphyritic granite. — This name has been sometimes given to that variety in which large crystals of felspar, sometimes more than an inch in length, are scattered through an ordinary base of granite. An example of this texture may be seen in the granite of the Land's End, in Cornwall. (Fig. 416.) The two larger prismatic crystals in this drawing represent felspar, smaller crystals of which are also seen, similar in form, scattered through the base. In this base also appear black specks of mica, the crystals of

which have a more or less perfect hexagonal outline. The remainder of the mass is quartz,

Fig. 416.



Porphyritic granite. Land's End, Cornwall.

the translucency of which is strongly contrasted to the opaqueness of the white felspar and black mica. But neither the transparency of the quartz, nor the silvery lustre of the mica, can be expressed in the engraving.

The uniform mineral character of large masses of granite seems to indicate that large quantities of the component elements were thoroughly mixed up together, and then crystallized under precisely similar conditions. There are, however, many accidental, or "occasional," minerals as they are termed, which belong to granite. Among these black schorl or tourmaline, actinolite, zircon, garnet, and fluor spar, are not uncommon; but they are too sparingly dispersed to modify the general aspect of the rock. They show, nevertheless, that the ingredients were not everywhere exactly the same; and a still

greater variation may be traced in the ever-varying proportions of the felspar, quartz, and mica.

Syenite.—When hornblende is the substitute for mica, which is very commonly the case, the rock becomes Syenite : so called from the celebrated ancient quarries of Syene in Egypt. It has all the appearance of ordinary granite, except when mineralogically examined in hand specimens, and being fully entitled to rank as a geological member of the same plutonic family as granite. Syenite, however, after maintaining the granitic character throughout extensive regions, is not uncommonly found to lose its quartz, and to pass insensibly into Syenitic greenstone, a rock of the trap family. Werner considered syenite as a binary compound of felspar and hornblende, and regarded quartz as merely one of its occasional minerals.

Syenitic-granite.—The quadruple compound of quartz, felspar, mica, and hornblende, may be so termed. This rock occurs in Scotland and in Guernsey.

Talcose granite, or Protogine of the French, is a mixture of felspar, quartz, and talc. It abounds in the Alps, and in some parts of Cornwall, producing by its decomposition the china clay, more than 12,000 tons of which are annually exported from that country for the potteries.*

* Boase on Primary Geology, p. 16.

Schorl rock, and schorly granite.—The former of these is an aggregate of schorl, or tourmaline, and quartz. When felspar and mica are also present, it may be called schorly granite. This kind of granite is comparatively rare.

Eurite.—A rock in which all the ingredients of granite are blended into a finely granular mass. Crystals of quartz and mica are sometimes scattered through the base of Eurite.

Pegmatite.—A name given by French writers to a variety of granite; a granular mixture of quartz and felspar; frequent in granite veins; passes into graphic granite.

All these granites pass into certain kinds of trap, a circumstance which affords one of many arguments in favor of what is now the prevailing opinion, that the granites are also of igneous origin. The contrast of the most crystalline form of granite, to that of the most common and earthy trap, is undoubtedly great; but each member of the volcanic class is capable of becoming porphyritic, and the base of the porphyry may be more and more crystalline, until the mass passes to the kind of granite most nearly allied in mineral composition.

The minerals which constitute alike the granitic and volcanic rocks, consist, almost exclusively, of seven elements, namely, silica, alumina, magnesia, lime, soda, potash, and iron; and these may some-

times exist in about the same proportions in a porous lava, a compact trap, or a crystalline granite. It may perhaps be found, on farther examination, for on this subject we have yet much to learn, that the presence of these elements in certain proportions is more favourable than in others to their assuming a crystalline or true granitic structure ; but it is also ascertained by experiment, that the same materials may, under different circumstances, form very different rocks. The same lava, for example, may be glassy, or scoriaceous, or stony, or porphyritic, according to the more or less rapid rate at which it cools ; and some trachytes and syenitic-greenstones may doubtless form granite and syenite, if the crystallization take place slowly.

It would be easy to multiply examples and authorities to prove the gradation of the granitic into the trap rocks. On the western side of the fiord of Christiania, in Norway, there is a large district of trap, chiefly greenstone-porphry, and syenitic-greenstone, resting on fossiliferous strata. To this, on its southern limit, succeeds a region equally extensive of syenite, the passage from the volcanic to the plutonic rock being so gradual that it is impossible to draw a line of demarcation between them.

“The ordinary granite of Aberdeenshire,” says Dr. MacCulloch, “is the usual ternary compound

of quartz, felspar, and mica ; but sometimes hornblende is substituted for the mica. But in many places a variety occurs which is composed simply of felspar and hornblende ; and in examining more minutely this duplicate compound, it is observed in some places to assume a fine grain, and at length to become undistinguishable from the greenstones of the trap family. It also passes in the same uninterrupted manner into a basalt, and at length into a soft claystone, with a schistose tendency on exposure, in no respect differing from those of the trap islands of the western coast." * The same author mentions, that in Shetland, a granite composed of hornblende, mica, felspar, and quartz, graduates in an equally perfect manner into basalt.†

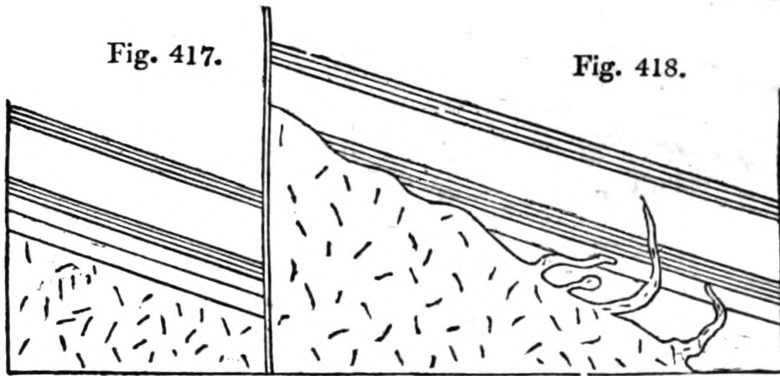
In Hungary there are varieties of trachyte, which, geologically speaking, are of modern origin, in which crystals, not only of mica, but of quartz, are common, together with felspar and hornblende. It is easy to conceive how such volcanic masses may, at a certain depth from the surface, pass downwards into granite.

I have already hinted at the close analogy in the forms of certain granitic and trappean veins ; and it will be found that strata penetrated by plutonic rocks have suffered changes very similar

* Syst. of Geol., vol. i. p. 157.

† Ibid., p. 158.

to those exhibited near the contact of volcanic dikes. Thus, in Glen Tilt, in Scotland, alternating strata of limestone and argillaceous schist come in contact with a mass of granite. The contact does not take place as might have been looked for, if the granite had been formed there before the strata were deposited, in which case the section would have appeared as in Fig. 417.; but the union is as represented in Fig. 418., the



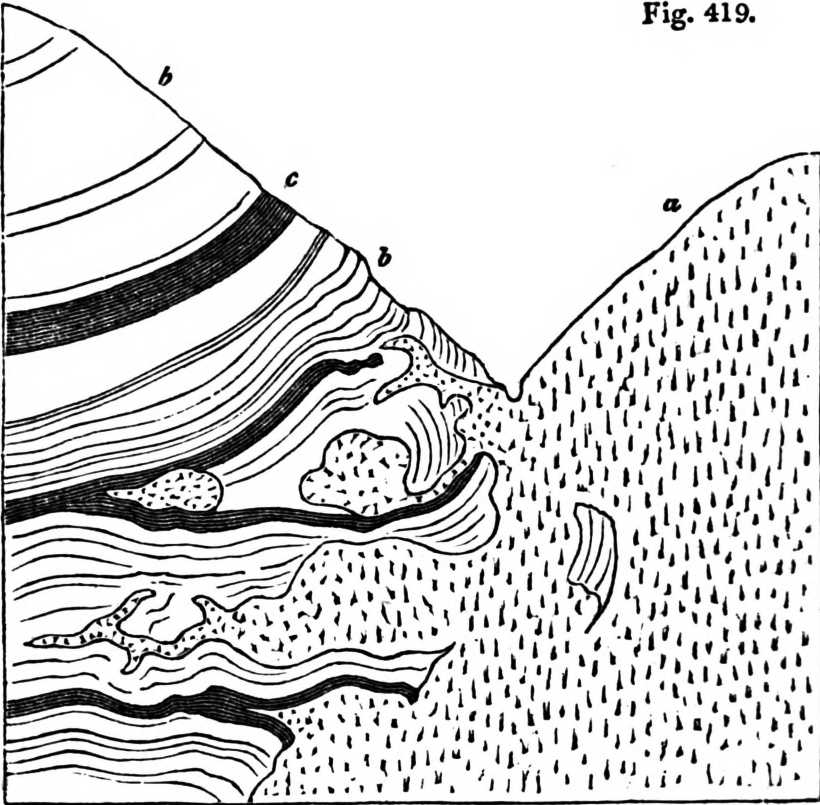
*Junction of granite and argillaceous schist in Glen Tilt. (MacCulloch.)**

undulating outline of the granite intersecting different strata, and occasionally intruding itself in tortuous veins into the beds of clay-slate and limestone, from which it differs so remarkably in composition. The limestone is sometimes changed in character by the proximity of the granitic mass or its veins, and acquires a more compact texture, like that of hornstone or chert, with a splintery fracture, effervescing feebly with acids.

* Geol. Trans., First Series, vol. iii. pl. 21.

The annexed diagram (Fig. 419.) represents another junction, in the same district, where the

Fig. 419.



Junction of granite and limestone in Glen Tilt. (MacCulloch.)

a. Granite.

b. Limestone.

c. Blue argillaceous schist.

granite sends forth so many veins as to reticulate the limestone and schist, the veins diminishing towards their termination to the thickness of a leaf of paper or a thread. In some places fragments of granite appear entangled, as it were, in the limestone, and are not visibly connected with any larger mass; while sometimes, on the other

hand, a lump of the limestone is found in the midst of the granite. The ordinary colour of the limestone of Glen Tilt is lead blue, and its texture large-grained and highly crystalline ; but where it approximates to the granite, particularly where it is penetrated by the smaller veins, the crystalline texture disappears, and it assumes an appearance exactly resembling that of hornstone. The associated argillaceous schist often passes into hornblende slate, where it approaches very near to the granite.*

The conversion of the limestone in these and many other instances into a siliceous rock, effervescing slowly with acids, would be difficult of explanation, were it not ascertained that such limestones are always impure, containing grains of quartz, mica, or felspar disseminated through them. The elements of these minerals, when the rock has been subjected to great heat, may have been fused, and so spread more uniformly through the whole mass.

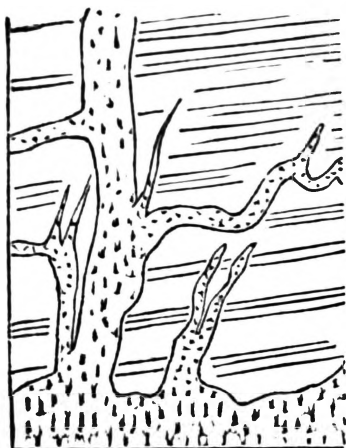
In the plutonic, as in the volcanic rocks, there is every gradation from a tortuous vein to the most regular form of a dike, such as intersect the tuffs and lavas of Vesuvius and Etna. Dikes of granite may be seen, among other places, on the southern flank of Mount Battock, one of the

* MacCulloch, Geol. Trans., vol. iii. p. 259.

Grampians, the opposite walls sometimes preserving an exact parallelism for a considerable distance.

As a general rule, however, granite veins in all quarters of the globe are more sinuous in their course than those of trap. They present

Fig. 420.



*Granite veins traversing clay slate, Table Mountain, Cape of Good Hope.**

similar shapes at the most northern point of Scotland, and the southernmost extremity of Africa, as the annexed drawings will show.

It is not uncommon for one set of granite veins to intersect another; and sometimes there are three sets, as in the environs of Heidelberg, where the granite on the banks of

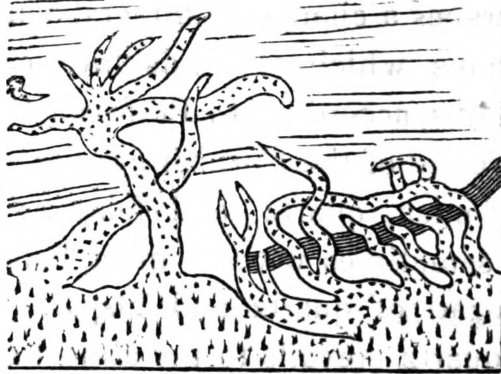
the river Necker is seen to consist of three varieties, differing in colour, grain, and various peculiarities of mineral composition. One of these, which is evidently the second in age, is seen to cut through an older granite; and another, still newer, traverses both the second and the first.

In Shetland there are two kinds of granite. One of them, composed of hornblende, mica, felspar, and quartz, is of a dark colour, and is seen

* Capt. B. Hall, Trans. Roy. Soc. Edin., vol. vii.

underlying gneiss. The other is a red granite, which penetrates the dark variety everywhere in veins.*

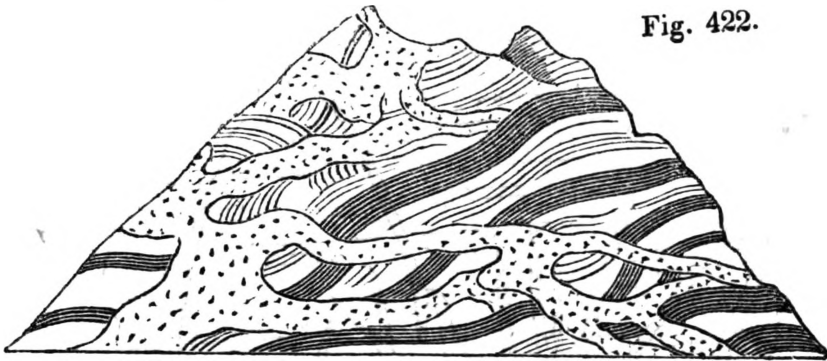
Fig. 421.



Granite veins traversing gneiss, Cape Wrath. (MacCulloch.)†

The accompanying sketches will explain the manner in which granite veins often ramify and cut each other. (Figs. 421. and 422.) They re-

Fig. 422.



Granite veins traversing gneiss at Cape Wrath, in Scotland. (MacCulloch.)

present the manner in which the gneiss at Cape Wrath, in Sutherlandshire, is intersected by veins.

* MacCulloch, *Syst. of Geol.*, vol. i. p. 58.

† *Western Islands*, pl. 31.

Their light colour, strongly contrasted with that of the hornblende-schist, here associated with the gneiss, renders them very conspicuous.

Granite very generally assumes a finer grain, and undergoes a change in mineral composition, in the veins which it sends into contiguous rocks. Thus, according to Professor Sedgwick, the main body of the Cornish granite is an aggregate of mica, quartz, and felspar; but the veins are sometimes without mica, being a granular aggregate of quartz and felspar. In other varieties quartz prevails to the almost entire exclusion both of felspar and mica; in others, the mica and quartz both disappear, and the vein is simply composed of white granular felspar.*

Fig. 423. is a sketch of a group of granite veins

Fig. 423.



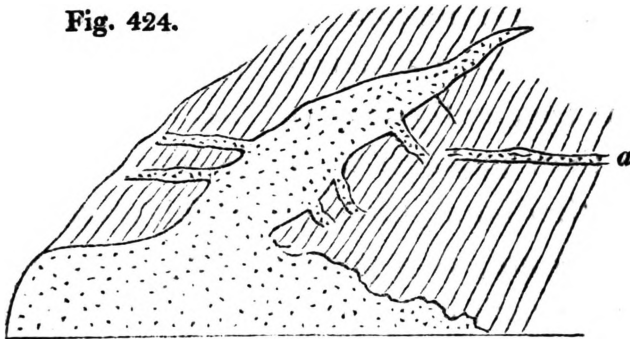
Granite veins, assing through hornblende slate, Carnsilver Cove, Cornwall.

* On Geol. of Cornwall, Camb. Trans., vol. i, p. 124,

in Cornwall, given by Messrs. Von Oeynhausen and Von Dechen.* The main body of the granite here is of a porphyritic appearance, with large crystals of felspar ; but in the veins it is fine-grained, and without these large crystals. The general height of the veins is from sixteen to twenty feet, but some are much higher.

In the Valorsine, a valley not far from Mont Blanc, in Switzerland, an ordinary granite, consisting of felspar, quartz, and mica, sends forth veins into a talcose gneiss (or stratified protogine), and in some places lateral ramifications are thrown off from the principal veins at right angles (see Fig. 424.), the veins, especially the minuter ones, being finer grained than the granite in mass.

Fig. 424.



Veins of granite in talcose gneiss. (L. A. Necker.)

It is here remarked, that the schist and granite, as they approach, seem to exercise a reciprocal

* Phil. Mag. and Annals, No. 27. New Series, March, 1829.

influence on each other, for both undergo a modification of mineral character. The granite, still remaining unstratified, becomes charged with green particles ; and the talcose gneiss assumes a granitiform structure, without losing its stratification.*

Professor Keilhau drew my attention to several localities in the country near Christiania, where the mineral character of gneiss appears to have been affected by a granite of much newer origin, for some distance from the point of contact. The gneiss, without losing its laminated structure, seems to have become charged with a larger quantity of felspar, and that of a redder colour, than the felspar usually belonging to the gneiss of Norway.

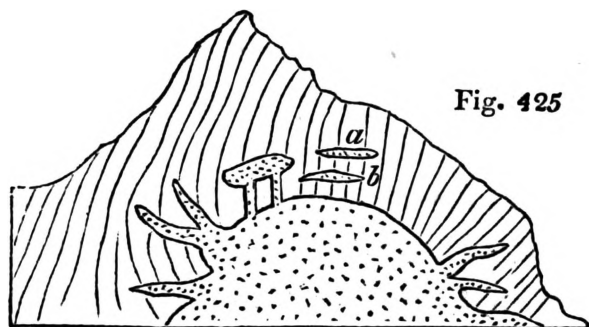
Granite, syenite, and those porphyries which have a granitiform structure, in short all plutonic rocks, are frequently observed to contain metals, at or near their junction with stratified formations. On the other hand, the veins which traverse stratified rocks are, as a general law, more metalliferous near such junctions than in other positions. Hence it has been inferred that these metals may have been spread in a gaseous form through the fused mass, and that the contact of another rock, in a different state of temperature, or sometimes

* Necker, sur la Val. de Valorsine, *Mém. de la Soc. de Phys. de Genève*, 1828.—I visited, in 1832, the spot referred to in Fig. 424.

the existence of rents in other rocks in the vicinity, may have caused the sublimation of the metals.*

There are many instances, as at Markerud, near Christiania, in Norway, where the strike of the beds has not been deranged throughout a large area by the intrusion of granite, both in large masses and in veins. This fact is considered by some geologists to militate against the theory of the forcible injection of granite in a fluid state. But it may be stated in reply, that ramifying dikes of trap, which almost all now admit to have been once fluid, pass through the same fossiliferous strata, near Christiania, without deranging their strike or dip.†

The real or apparent isolation of large or small



General view of junction of granite and schist of the Valorsins.
(L. A. Necker.)

masses of granite detached from the main body, as at *a b*, Fig. 425., and above, Fig. 419., and *a*,

* Necker, *Proceedings of Geol. Soc.*, No. 26. p. 392.

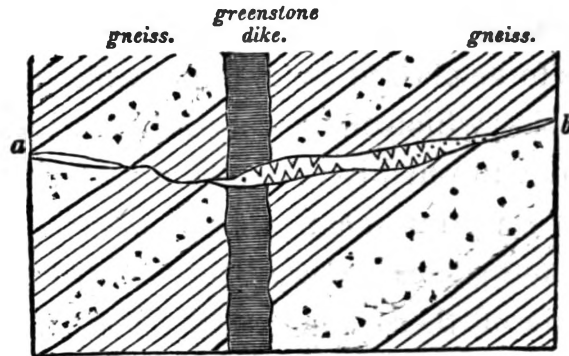
† See Keilhau's *Gæa Norvegica*; Christiania, 1838.

Fig. 424., has been thought by some writers to be irreconcilable with the doctrine usually taught respecting veins ; but many of them may, in fact, be sections of root-shaped prolongations of granite ; while, in other cases, they may in reality, be detached portions of rock having the plutonic structure. For there may have been spots in the midst of the invaded strata, in which there was an assemblage of materials more fusible than the rest, or more fitted to combine readily into some form of granite.

Veins of pure quartz are often found in granite, as in many stratified rocks, but they are not traceable, like veins of granite or trap, to large bodies of rock of similar composition. They appear to have been cracks, into which siliceous matter was infiltrated. Such segregation, as it is called, can sometimes be shown to have clearly taken place long subsequently to the original consolidation of the containing rock. Thus, for example, in the gneiss of Tronstad Strand, near Drammen, in Norway, the annexed section is seen on the beach. It appears that the alternating strata of whitish granitiform gneiss, and black hornblende-schist, were first cut through by a greenstone dike about $2\frac{1}{2}$ feet wide ; then the crack *a b* passed through all these rocks, and was filled up with quartz. The opposite walls of the vein are in some parts incrustated with transparent crystals of quartz, the

middle of the vein being filled up with common opaque white quartz.

Fig. 426.

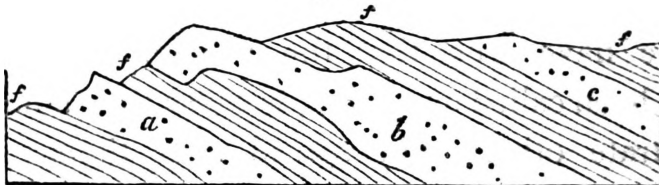


a. b. Quartz vein passing through gneiss and greenstone,
Tronsd Strand, near Christiania.

We have seen that the volcanic formations have been called overlying, because they not only penetrate others, but spread over them. Mr. Necker has proposed to call the granites the underlying igneous rocks, and the distinction here indicated is highly characteristic. It was indeed supposed by Von Buch, at the commencement of his geological career, that the granite of Christiania, in Norway, was sometimes intercalated in mountain masses between the transition strata of that country, overlying fossiliferous shale and limestone. But although the granite sends veins into these fossiliferous rocks, and is decidedly posterior in origin, the opinion expressed of its actual superposition in mass has been disproved by Professor Keilhau, some of whose observations respecting localities referred to by Von Buch, I had oppor-

tunities in 1837 of verifying. There are, however, on a smaller scale, certain beds of euritic porphyry, some a few feet, others many yards in thickness, which pass into granite, and deserve perhaps to be classed as plutonic rather than trap-pean rocks, which may truly be described as interposed conformably between fossiliferous strata, as the porphyries (*a c*, Fig. 427.), which divide the bituminous shales and argillaceous limestones, *ff*. But some of these same porphyries are partially

Fig. 427.



*Euritic porphyry alternating with fossiliferous transition strata,
near Christiania.*

unconformable, as *b*, and may lead us to suspect that the others also, notwithstanding their appearance of interstratification, have been forcibly injected. Some of the porphyritic rocks above mentioned are highly quartzose, others very felspathic. In proportion as the masses are more voluminous, they become more granitic in their texture, less conformable, and even begin to send forth veins into contiguous strata. In a word, we have here a beautiful illustration of the intermediate gradations between volcanic and plutonic rocks, not only in their mineralogical composition

and structure, but also in their relations of position to associated formations. If the term overlying can in this instance be applied to a plutonic rock, it is only in proportion as that rock begins to acquire a trappean aspect.

It has been already hinted that the heat, which in every active volcano extends downwards to indefinite depths, must produce simultaneously very different effects near the surface, and far below it; and we cannot suppose that rocks resulting from the crystallizing of fused matter under a pressure of several miles of the earth's crust can resemble those formed at or near the surface. Hence the production at great depths of a class of rocks analogous to the volcanic, and yet differing in many particulars, might almost have been predicted, even had we no plutonic formations to account for. How well these agree, both in their positive and negative characters, with the theory of their deep subterranean origin, the student will be able to judge by considering the descriptions already given.

It has, however, been objected, that if the granitic and volcanic rocks were simply different parts of one great series, we ought to find in mountain chains volcanic dikes passing upwards into lava, and downwards into granite. But we may answer, that our vertical sections are usually of small extent; and if we find in certain places

a transition from trap to porous lava, and in others a passage from granite to trap, it is as much as could be expected of this evidence.

The prodigious extent of denudation which has been already demonstrated to have occurred at former periods, will reconcile the student to the belief that crystalline rocks of high antiquity, although deep in the earth's crust when originally formed, may have become uncovered and exposed at the surface. Their actual elevation above the sea may be referred to the same causes to which we have attributed the upheaval of marine strata, even to the summits of some mountain chains. But to these and other topics, I shall revert when speaking, in the next chapter, of the relative ages of different masses of granite.

CHAPTER XXXIII.

ON THE DIFFERENT AGES OF THE PLUTONIC ROCKS.

Difficulty in ascertaining the precise age of a plutonic rock—Test of age by relative position—Test by intrusion and alteration—Test by mineral composition—Test by included fragments—Recent and Pliocene plutonic rocks, why invisible—Tertiary plutonic rocks in the Andes—Granite altering Cretaceous rocks—Granite altering Lias in the Alps and in Sky—Granite of Dartmoor altering Carboniferous strata—Granite of the Old Red sandstone period—Syenite altering Silurian strata in Norway—Blending of the same with gneiss—Most ancient plutonic rocks—Granite protruded in a solid form—On the probable age of the granites of Arran, in Scotland.

WHEN we adopt the igneous theory of granite, as explained in the last chapter, and believe that different plutonic rocks have originated at successive periods beneath the surface of the planet, we must be prepared to encounter greater difficulty in ascertaining the precise age of such rocks, than in the case of volcanic and fossiliferous formations. We must bear in mind, that the evidence of the age of each contemporaneous volcanic rock was derived, either from lavas poured out upon the ancient surface, whether in the sea or in the atmosphere, or from tuffs and conglomerates, also deposited at the surface, and

either containing organic remains themselves, or intercalated between strata containing fossils. But all these tests fail when we endeavour to fix the chronology of a rock, which has crystallized from a state of fusion in the bowels of the earth. In that case, we are reduced to the following tests ; 1st, relative position ; 2dly, intrusion, and alteration of the rocks in contact ; 3dly, mineral characters ; 4thly, included fragments.

Test of age by relative position. — Unaltered fossiliferous strata of every age are met with reposing immediately on plutonic rocks ; as at Christiania, in Norway, where the Newer Pliocene deposits rest on granite ; in Auvergne, where the freshwater Eocene strata, and at Heidelberg, on the Rhine, where the New Red sandstone, occupy a similar place. In all these, and similar instances, inferiority in position is connected with the superior antiquity of granite. The crystalline rock was solid before the sedimentary beds were superimposed, and the latter usually contain in them rounded pebbles of the subjacent granite.

Test by intrusion and alteration. — But when plutonic rocks send veins into strata, and alter them near the point of contact, in the manner before described (p. 335.), it is clear that, like intrusive traps, they are newer than the strata which they invade and alter. Examples of the application of this test will be given in the sequel.

Test by mineral composition.—Notwithstanding a general uniformity in the aspect of plutonic rocks, we have seen in the last chapter that there are many varieties, such as Syenite, Talcose granite, and others. One of these varieties is sometimes found exclusively prevailing throughout an extensive region, where it preserves a homogeneous character; so that having ascertained its relative age in one place, we can easily recognise its identity in others, and thus determine from a single section the chronological relations of large mountain masses. Having observed, for example, that the syenitic granite of Norway, in which the mineral called zircon abounds, has altered the Silurian strata wherever it is in contact, we do not hesitate to refer all masses of the same zircon-syenite in the south of Norway to the same era. (See p. 402.)

Some have imagined that the age of different granites might, to a great extent, be determined by their mineral characters alone; syenite, for instance, or granite with hornblende, being more modern than common or micaceous granite. But modern investigations have proved these generalizations to have been premature. The syenitic granite of Norway already alluded to may be of the same age as the Silurian strata, which it traverses and alters, or may belong to the Old Red sandstone period; whereas the granite of Dart-

moor, although consisting of mica, quartz, and felspar, is newer than the Coal. (See p. 364.)

Test by included fragments.—This criterion can rarely be of much importance, because the fragments involved in granite are usually so much altered, that they cannot be referred with certainty to the rocks whence they were derived. In the White Mountains, in North America, according to Professor Hubbard, a granite vein traversing granite, contains fragments of slate and trap, which must have fallen into the fissure when the fused materials of the vein were injected from below,* and thus the granite is shown to be newer than certain superficial slaty and trappean formations.

Recent and Pliocene plutonic rocks, why invisible.—The explanation already given in the 28th and in the last chapter of the probable relation of the plutonic to the volcanic formations, will naturally lead the reader to infer, that rocks of the one class can never be produced at or near the surface without some members of the other being formed below simultaneously, or soon afterwards. It is not uncommon for lava streams to require more than ten years to cool in the open air ; and where they are of great depth, a much longer period. The melted matter poured from Jorullo, in Mexico, in the year

* Silliman's Journ., No. 69. p. 123.

1759, which accumulated in some places to the height of 550 feet, was found to retain a high temperature half a century after the eruption.* We may conceive, therefore, that great masses of subterranean lava may remain in a red-hot or incandescent state in the volcanic foci for immense periods, and the process of refrigeration may be extremely gradual. Sometimes, indeed, this process may be retarded for an indefinite period, by the accession of fresh supplies of heat; for we find that the lava in the crater of Stromboli, one of the Lipari islands, has been in a state of constant ebullition for the last two thousand years; and we may suppose this fluid mass to communicate with some caldron or reservoir of fused matter below. In the Isle of Bourbon, also, where there has been an emission of lava once in every two years for a long period, the lava below can scarcely fail to have been permanently in a state of liquefaction. If then it be a reasonable conjecture, that about 2000 volcanic eruptions occur in the course of every century, either above the waters of the sea or beneath them,† it will follow, that the quantity of plutonic rock generated, or in progress during the Recent epoch, must already have been considerable.

But as the plutonic rocks originate at some

* See "Principles," Index, "Jorullo."

† Ibid., Index, "Volcanic Eruptions,"

depth in the earth's crust, they can only be rendered accessible to human observation, by subsequent upheaval and denudation. Between the period when a plutonic rock crystallizes in the subterranean regions, and the era of its protrusion at any single point of the surface, one or two geological periods must usually intervene. Hence, we must not expect to find the Recent or Newer Pliocene granites laid open to view, unless we are prepared to assume that sufficient time has elapsed since the commencement of the Newer Pliocene period for great upheaval and denudation. A plutonic rock, therefore, must, in general, be of considerable antiquity relatively to the fossiliferous and volcanic formations, before it becomes extensively visible. As we know that the upheaval of land has been sometimes accompanied in South America by volcanic eruptions and the emission of lava, we may conceive the more ancient plutonic rocks to be forced upwards to the surface by the newer rocks of the same class formed successively below,—subterposition in the plutonic, like superposition in the sedimentary rocks, being usually characteristic of a newer origin.

In the accompanying diagram, Fig. 428., an attempt is made to show the inverted order in which sedimentary and plutonic formations may occur in the earth's crust.

Fig. 428.

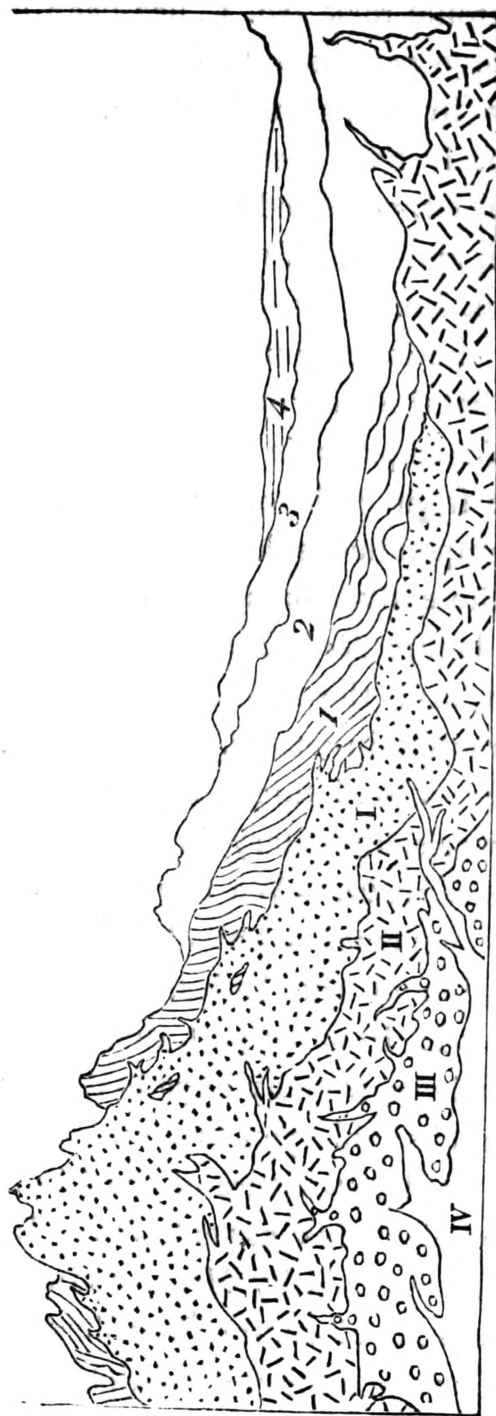


Diagram showing the relative position which the plutonic and sedimentary formations of different ages may occupy.

- | | |
|-------------------------|----------------------------------|
| I. Primary plutonic. | 4. Recent strata. |
| II. Secondary plutonic. | 3. Tertiary strata. |
| III. Tertiary plutonic. | 2. Secondary strata. |
| IV. Recent plutonic. | 1. Primary fossiliferous strata. |

The metamorphic rocks are not indicated in this diagram, but the student may learn from the Frontispiece what place they would occupy if portions of the strata Nos. 1. and 2., invaded by granite, had become metamorphic.

The oldest plutonic rock, No. I., has been upheaved at successive periods until it has become exposed to view in a mountain-chain. This protrusion of No. I. has been caused by the igneous agency which produced the new plutonic rocks Nos. II. III. and IV. Part of the primary fossiliferous strata, No. 1., have also been raised to the surface by the same gradual process. It will be observed that the Recent *strata* No.4., and the Recent *granite* or plutonic rock No. IV., are the most remote from each other in position, although of contemporaneous date. According to this hypothesis, the convulsions of many periods will be required before *Recent* granite will be upraised so as to form the highest ridges and central axes of mountain-chains. During that time the *Recent* strata No.4. might be covered by a great many newer sedimentary formations.

Tertiary plutonic rocks.—We have seen that great upheaving movements have been experienced in the region of the Andes, during the Post-Pliocene period. In some part, therefore, of this chain, if any where, we may hope to discover tertiary plutonic rocks laid open to view. What we already know of the structure of the Chilian Andes seems to realize this expectation. In a transverse section, examined by Mr. Darwin, between Valparaiso and Mendoza, the Cordillera was found to consist of two separate and parallel chains,

formed of sedimentary rocks of different ages, the strata in both resting on plutonic rocks, by which they have been altered. In the western or oldest range, called the Peuquenes, are black calcareous clay-slates, rising to the height of nearly 14,000 feet above the sea, in which are shells of the genera *Gryphæa*, *Turritella*, *Terebratula*, and *Ammonite*. These rocks are supposed to be of the age of the central parts of the secondary series of Europe. They are penetrated and altered by dikes and mountain masses of a plutonic rock, which has the texture of ordinary granite, but rarely contains quartz, being a compound of albite and hornblende.

The second or eastern chain consists chiefly of sandstones and conglomerates, of vast thickness, the materials of which are derived from the ruins of the western chain. The pebbles of the conglomerates are, for the most part, rounded fragments of the fossiliferous slates before mentioned. The resemblance of the whole series to certain tertiary deposits on the shores of the Pacific, not only in mineral character, but in the imbedded lignite and silicified wood, leads to the conjecture that they also are tertiary. Yet these strata are not only associated with trap rocks and volcanic tuffs, but are also altered by a granite newer than that of the western chain, and consisting of quartz, felspar, and talc. They are traversed, moreover,

by dikes of the same granite, and by numerous veins of iron, copper, arsenic, silver, and gold ; all of which can be traced to the underlying granite.* We have, therefore, strong ground to presume that the plutonic rock, here exposed on a large scale in the Chilian Andes, is of later date than certain tertiary formations.

But the theory adopted in this work of the subterranean origin of the hypogene formations would be untenable, if the supposed fact here alluded to, of the appearance of tertiary granite at the surface, was not a rare exception to the general rule. A considerable lapse of time must intervene between the formation in the nether regions of plutonic and metamorphic rocks, and their emergence at the surface. For a long series of subterranean movements must occur before such rocks can be uplifted into the atmosphere or the ocean ; and, before they can be rendered visible to man, some strata which previously covered them must usually have been stripped off by denudation.

We know that in the Bay of Baiæ, in 1538, in Cutch in 1819, and on several occasions in Peru and Chili, since the commencement of the present century, the permanent upheaval or subsidence of land has been accompanied by the

* Darwin, pp. 390. 406.

simultaneous emission of lava at one or more points in the same volcanic region. From these and other examples it may be inferred that the rising or sinking of the earth's crust, operations by which sea is converted into land and land into sea, are a part only of the consequences of subterranean igneous action. It can scarcely be doubted that this action consists, in a great degree, of the baking, and occasionally the liquefaction, of rocks, causing them to assume, in some cases a larger, in others a smaller, volume than before the application of heat. It consists also in the generation of gases, and their expansion by heat, and the injection of liquid matter into rents formed in superincumbent rocks. The prodigious scale on which these subterranean causes have operated in Sicily since the deposition of the Newer Pliocene strata will be appreciated, when we remember that throughout half the surface of that island such strata are met with, raised to the height of from 50 to that of 2000, and even 3000 feet above the level of the sea. In the same island also the older rocks which are contiguous to these marine tertiary strata must have undergone, within the same period, a similar amount of upheaval.

The like observations may be extended to nearly the whole of Europe, for, since the commencement of the Eocene period, the entire Eu-

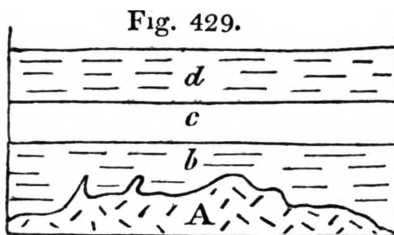
ropean area, as I have elsewhere shown,* has, with the exception of a few districts, emerged from the deep to its present altitude, and even those tracts, which were already dry land before the Eocene era, have almost everywhere acquired additional height. A large amount of subsidence has also occurred during the same period, so that the extent of the subterranean spaces which have either become the receptacles of sunken fragments of the earth's crust, or have been rendered capable of supporting other fragments at a much greater height than before, must be so great that they probably equal, if not exceed in volume, the entire continent of Europe. We are entitled, therefore, to ask what amount of change of equivalent importance can be proved to have occurred in the earth's crust within an equal quantity of time anterior to the Eocene epoch? They who contend for the more intense energy of subterranean causes in the remoter eras of the earth's history, may find it more difficult to give an answer to this question than they anticipated.

The principal effect of volcanic action in the nether regions, during the tertiary period, seems to have consisted in the upheaval to the surface of

* See Map of Europe and Explanation, in Principles, book i.

hypogene formations of an age anterior to the carboniferous. The repetition of another series of movements, of equal violence, might upraise the plutonic and metamorphic rocks of many secondary periods; and if the same force should still continue to act, the next convulsions might bring up to the day the *tertiary* and *recent* hypogene rocks. In the course of such changes many of the existing sedimentary strata would suffer greatly by denudation, others might assume a metamorphic structure, or become melted down into plutonic and volcanic rocks. Meanwhile the deposition of a vast thickness of new strata would not fail to take place during the upheaval and partial destruction of the older rocks. But I must refer the reader to the last chapter of this volume (see p. 426.) for a fuller explanation of these views.

Cretaceous period. — It will be shown in the next chapter that chalk as well as lias has been altered by granite in the eastern Pyrenees. Whether such granite be cretaceous or tertiary



cannot easily be decided. Suppose *b*, *c*, *d*, to be three members of the Cretaceous series, the lowest of which, *b*, has been altered by the

granite A, the modifying influence not having

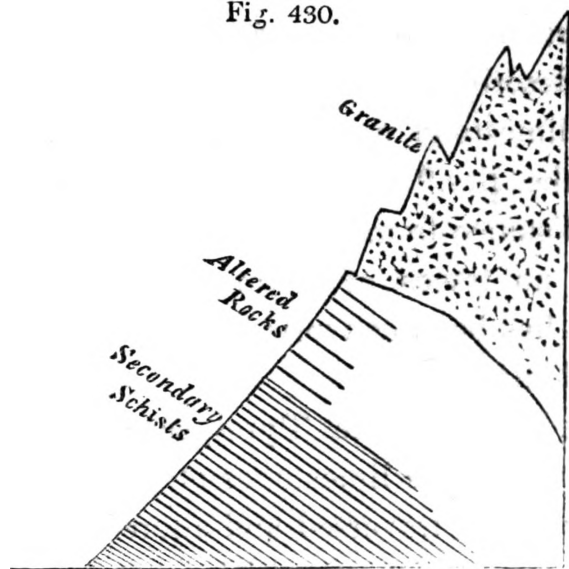
extended so far as *c*, or having but slightly affected its lowest beds. Now it can rarely be possible for the geologist to decide whether the beds *d* existed at the time of the intrusion of *A*, and alteration of *b* and *c*, or whether they were subsequently thrown down upon *c*.

As some Cretaceous rocks, however, have been raised to the height of more than 9000 feet in the Pyrenees, we must not assume that plutonic formations of the same age may not have been brought up and exposed by denudation, at the height of 2000 or 3000 feet on the flanks of that chain.

Period of Oolite and Lias.—In the department of the Hautes Alpes, in France, near Vizille, M. Elie de Beaumont traced a black argillaceous limestone, charged with belemnites, to within a few yards of a mass of granite. Here the limestone begins to put on a granular texture, but is extremely fine-grained. When nearer the junction it becomes grey, and has a saccharoid structure. In another locality, near Champoleon, a granite composed of quartz, black mica, and rose-coloured felspar, is observed partly to overlies the secondary rocks, producing an alteration which extends for about thirty feet downwards, diminishing in the beds which lie farthest from the granite. (See Fig. 430.) In the altered mass the argillaceous beds are hardened, the limestone is saccharoid, the gritz quartzose, and

in the midst of them a thin layer of an imperfect granite. It is also an important circumstance,

Fig. 430.



Junction of granite with Jurassic or Oolite strata in the Alps, near Champoleon.

that near the point of contact, both the granite and the secondary rocks become metalliferous, and contain nests and small veins of blende, galena, iron, and copper pyrites. The stratified rocks become harder and more crystalline, but the granite, on the contrary, softer and less perfectly crystallized near the junction.*

Although the granite is incumbent in the above section (Fig. 430.), we cannot assume that it overflowed the strata, for the disturbances of

* Elie de Beaumont, sur les Montagnes de l'Oisans, &c. Mém. de la Soc. d'Hist. Nat. de Paris, tom. v.

the rocks are so great in this part of the Alps that they seldom retain the position which they must originally have occupied.

A considerable mass of syenite, in the Isle of Sky, is described by Dr. MacCulloch as intersecting limestone and shale, which are of the age of the lias.* The limestone, which, at a greater distance from the granite, contains shells, exhibits no traces of them near its junction, where it has been converted into a pure crystalline marble.†

At Predazzo, in the Tyrol, secondary strata, some of which are limestones of the Oolitic period, have been traversed and altered by plutonic rocks, one portion of which is an augitic porphyry, which passes insensibly into granite. The limestone is changed into granular marble, with a band of serpentine at the junction.‡

Carboniferous period.—The granite of Dartmoor, in Devonshire, was formerly supposed to be one of the most ancient of the plutonic rocks, but is now ascertained to be posterior in date to the culm-measures of that country, which, from their position, and as containing true coal-plants,

* See Murchison, Geol. Trans., 2nd series, vol. ii. part ii. pp. 311–321.

† Western Islands, vol. i. p. 330. plate 18. figs. 3, 4.

‡ Von Buch, Annales de Chimie, &c.

are regarded by Professor Sedgwick and Mr. Murchison as members of the true carboniferous series. This granite, like the syenitic granite of Christiania, has broken through the stratified formations without much changing their strike. Hence, on the north-west side of Dartmoor, the successive members of the culm-measures abut against the granite, and become metamorphic as they approach. These strata are also penetrated by granite veins and plutonic dikes, called "elvans." * The granite of Cornwall is probably of the same date, and, therefore, as modern as the Carboniferous strata, if not much newer.

Old Red sandstone period. — The plutonic rocks of the Malvern Hills in Worcestershire, consist of a granitic compound of quartz, felspar, and hornblende, or occasionally of quartz, mica, and felspar, which passes into syenite and greenstone.† This rock has altered the adjacent Silurian strata into well characterized metamorphic schists, principally chloritic and micaceous-schist, with some gneiss, and has dislocated and reversed the position of the beds of the Silurian and Old Red sandstone. There are indications, says Mr. Murchison, of several periods of movement, by which the strata were forced up

* Proceedings of Geol. Soc., vol. ii. p. 562.

† Mr. L. Horner, Geol. Trans., 1st ser., vol. i. p. 281.

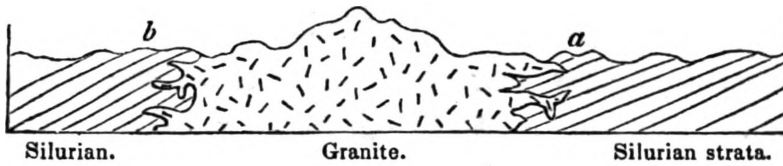
and folded back, but the chief outburst was after the accumulation of the Silurian and part of the Old Red System, and anterior to the formation of the coal-beds, which are undisturbed.*

Silurian period.—It has long been known that the granite near Christiania, in Norway, is of newer origin than the Silurian strata of that region. Von Buch first announced, in 1813, the discovery of its posteriority in date to limestones containing orthocerata and trilobites. The proofs consist in the penetration of granite veins into the shale and limestone, and the alteration of the strata, for a considerable distance from the point of contact, both of these veins and the central mass from which they emanate. (See p.345.) Von Buch supposed that the plutonic rock alternated with the fossiliferous strata, and that large masses of granite were sometimes incumbent upon the strata; but this idea was erroneous, and arose from the fact that the beds of shale and limestone often dip towards the granite up to the point of contact, appearing as if they would pass under it in mass, as at *a*, Fig. 431., and then again on the opposite side of the same mountain, as at *b*, dip away from the same granite. When the junctions, however, are carefully examined, it is found that the plutonic rock intrudes itself in veins, and no

* Silurian System, p. 425.

where covers the fossiliferous strata in large overlying masses, as is so commonly the case with trappean formations.*

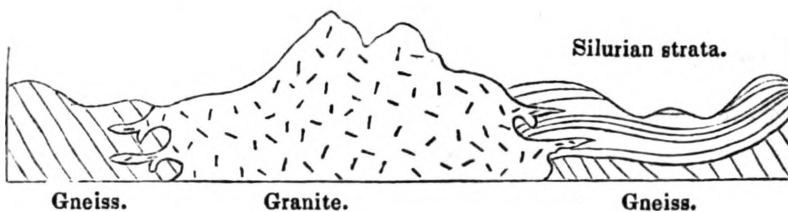
Fig. 431.



Now this granite, which is more modern than the Silurian strata of Norway, also sends veins in the same country into an ancient formation of gneiss; and the relations of the plutonic rock and the gneiss, at their junction, are full of interest when we duly consider the wide difference of epoch which must have separated their origin.

The length of this interval of time is attested by the following facts : — The fossiliferous, or

Fig. 432.



Granite sending veins into Silurian strata and Gneiss,— Christiania, Norway.

transition beds, rest unconformably upon the truncated edges of the gneiss, the inclined strata

* See the *Gæa Norvegica* and other works of Keilhau, with whom I examined this country.

of which had been disturbed and denuded before the sedimentary beds were superimposed (see Fig. 432.). The signs of denudation are twofold; first, the surface of the gneiss is seen occasionally on the removal of the newer beds, containing organic remains, to be scored and polished; secondly, pebbles of gneiss have been found in some of the transition strata. Between the origin, therefore, of the gneiss and the granite there intervened, first, the period when the strata of gneiss were inclined; secondly, the period when they were denuded; thirdly, the period of the deposition of the transition deposits. Yet the granite produced, after this long interval, is often so intimately blended with the ancient gneiss, at the point of junction, that it is impossible to draw any other than an arbitrary line of separation between them; and where this is not the case, tortuous veins of granite pass freely through gneiss, ending sometimes in threads, as if the older rock had offered no resistance to their passage. It seems necessary, therefore, to conceive that the gneiss was softened and more or less melted when penetrated by the granite. But had such junctions alone been visible, and had we not learnt, from other sections, how long a period elapsed between the consolidation of the gneiss, and the injection of this granite, we might have suspected that the gneiss was scarcely solidified, or had not yet assumed its com-

plete metamorphic character, when invaded by the plutonic rock. From this example we may learn how impossible it is to conjecture whether certain granites in Scotland, and other countries, which send veins into gneiss and other metamorphic rocks, are primary, or whether they may not belong to some secondary or tertiary period.

Most ancient granites.—It is not half a century since the doctrine was very general that all granitic rocks were *primitive*, that is to say, that they originated before the deposition of the first sedimentary strata, and before the creation of organic beings (see Vol. I. p. 18.). But so greatly are our views now changed, that we find it no easy task to point out a single mass of granite demonstrably more ancient than all the known fossiliferous deposits. Could we discover some Lower Cambrian strata resting immediately on granite, there being no alterations at the point of contact, nor any intersecting granitic veins, we might then affirm the plutonic rock to have originated before the oldest known fossiliferous strata. Still it would be presumptuous to suppose that when a small part only of the globe has been investigated, we are acquainted with the oldest fossiliferous strata in the crust of our planet. Even when these are found, we cannot assume that there never were any antecedent strata containing organic remains, which may have become metamorphic. If we find peb-

bles of granite in a conglomerate of the Lower Cambrian system, we may then feel assured that the parent granite was formed before the Lower Cambrian formation. But if the incumbent strata be merely Silurian or Upper Cambrian, the fundamental granite, although of high antiquity, may be posterior in date to *known* fossiliferous formations.

Protrusion of solid granite.—In part of Sutherlandshire, near Brora, common granite, composed of felspar, quartz, and mica, is in immediate contact with Oolitic strata, and has clearly been elevated to the surface at a period subsequent to the deposition of those strata.* Professor Sedgwick and Mr. Murchison conceive that this granite has been upheaved in a solid form ; and that in breaking through the submarine deposits, with which it was not perhaps originally in contact, it has fractured them so as to form a breccia along the line of junction. This breccia consists of fragments of shale, sandstone, and limestone, with fossils of the oolite, all united together by a calcareous cement. The secondary strata, at some distance from the granite, are but slightly disturbed, but in proportion to their proximity the amount of dislocation becomes greater.

If we admit that solid hypogene rocks, whether

* Murchison, Geol. Trans., 2nd series, vol. ii. p. 307.

stratified or unstratified, have in such cases been driven upwards so as to pierce through yielding sedimentary deposits, we shall be enabled to account for many geological appearances otherwise inexplicable. Thus, for example, at Weinböhla and Hohnstein, near Meissen, in Saxony, a mass of granite has been observed covering strata of the Cretaceous and Oolitic periods for the space of between 300 and 400 yards square. It appears clearly from a recent memoir of Dr. B. Cotta on this subject*, that the granite was thrust into its actual position when solid. There are no intersecting veins at the junction — no alteration as if by heat, but evident signs of rubbing, and a breccia in some places, in which pieces of granite are mingled with broken fragments of the secondary rocks. As the granite overhangs both the lias and chalk, so the lias is in some places bent over strata of the cretaceous era.

Relative age of the granites of Arran.— In this island, the largest in the Firth of Clyde, being twenty miles in length from north to south, the four great classes of rocks, the fossiliferous, volcanic, plutonic, and metamorphic, are all conspicuously displayed within a very small area, and with their peculiar characters strongly contrasted. In the north of the island the granite

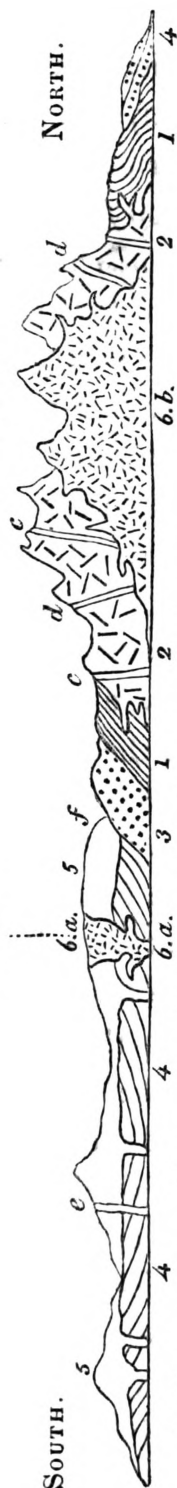
* Geognostische Wanderungen, Leipzig, 1838.

risers to the height of nearly 3000 feet above the sea, terminating in mountainous peaks. (See Section, Fig. 433.) On the flanks of the same mountains are chloritic-schists, blue roofing-slate, and other rocks of the metamorphic order (No. 1.), into which the granite (No. 2.) sends veins. This granite, therefore, is newer than the hypogene schists (No. 1.), which it penetrates.

These schists are highly inclined. Upon them rest beds of conglomerate and sandstone (No. 3.), which are referable to the Old Red formation, to which succeed various shales and limestones (No. 4.) containing the fossils of the Carboniferous period, upon which are other strata of sandstone and conglomerate (upper part of No. 4.), in which no fossils have been met with, which it is conjectured may belong to the New Red sandstone period. All the preceding formations are cut through by the volcanic rocks (No. 5.), which consist of greenstone, basalt, pitchstone, claystone-porphyry, and other varieties. These appear either in the form of dikes, or in dense masses from 50 to 700 feet in thickness, overlying the strata (No. 4). They sometimes pass into syenite of so crystalline a form, that it may rank as a plutonic formation, and in one region, at Ploverfield, in Glen Cloy, a fine-grained granite (6. *a.*) is seen associated with the trap formation, and sending veins into the sandstone or into the upper strata

*General Section of Arran from north to south.**Plaverfield.*

Fig. 433.



1. Metamorphic or Hypogene schists, the oldest formations in Arran.
2. Coarse-grained granite sending veins into the schists, No. 1.
3. Old Red Sandstone and Conglomerate containing pebbles exclusively derived from the rocks, No. 1., without any intermixture of granitic fragments.
4. Carboniferous strata and red sandstone (New Red?)
5. Trap, overlying and in dikes, passing occasionally into Syenites of the Plutonic class.
- 6 *a.* Fine-grained granite, associated with the overlying trap, No. 5.
- 6 *b.* Similar fine-grained granite, sending veins into the older granite, No. 2., and cutting off the trappean dikes, *c. d.**

* In the above section I have attempted to represent the new discoveries made since 1839, by Mr. Necker and Mr. A. C. Ramsay, in regard to the plutonic formations, 6. *a.* and 6. *b.*

of No. 4. This interesting discovery of granite in the southern region of Arran, at a point where it is separated from the northern mass of granite by a great thickness of secondary strata and overlying trap, was made by Mr. L. A. Necker of Geneva, during his survey of Arran in 1839. We also learn from the recent investigations of Mr. A. C. Ramsay, that a similar fine-grained granite (No. 6. *b.*) appears in the interior of the northern granitic district, forming the nucleus of it, and sending veins into the older coarse grained granite (No. 2.). The trap dikes which penetrate the older granite are cut off, according to Mr. Ramsay, at the junction of the fine grained.

It is not improbable that the granite (No. 6. *b.*) may be of the same age as that of Ploverfield (No. 6. *a.*), and this again may belong to the same geological epoch as the trap formations (No. 5.). If there be any difference of date, it would seem that the fine-grained granite must be newer than the trappean rocks. But on the other hand, the coarser granite (No. 2.) may be the oldest rock in Arran, with the exception of the hypogene slates (No. 1.), into which it sends veins.

An objection may perhaps, at first, be started to this conclusion, derived from the curious and striking fact, the importance of which was first emphatically pointed out by Dr. MacCulloch, that no pebbles of granite occur in the conglomerates

of the red sandstone in Arran, although these conglomerates are several hundred feet in thickness, and lie at the foot of lofty granite mountains, which tower above them. As a general rule, all such aggregates of pebbles and sand are mainly composed of the wreck of pre-existing rocks occurring in the immediate vicinity. The total absence therefore of granitic pebbles has justly been a theme of wonder to those geologists who have successively visited Arran, and they have carefully searched there, as I have done myself, to find an exception, but in vain. The rounded masses consist exclusively of quartz, chlorite-schist, and other members of the metamorphic series; nor in the newer conglomerates of No. 4. have any granitic fragments been discovered. Are we then entitled to affirm that the coarse-grained granite No. 2. like the fine grained variety No. 6. *a.* is more modern than all the other rocks of the island? This we cannot assume at present, but we may confidently infer that when the various beds of sandstone and conglomerate were formed, no granite had reached the surface, or had been exposed to denudation in Arran. It is clear that the crystalline schists were ground into sand and shingle when the strata No. 3. were deposited, and at that time the waves had never acted upon the granite, which now sends its veins into the schist. May we then conclude, that the

schists suffered denudation before they were invaded by granite? This opinion, although not inadmissible, is by no means fully borne out by the evidence. For at the time when the Old Red sandstone originated, the metamorphic strata may have formed islands in the sea, as in Fig. 434., over which the breakers rolled, or from

Fig. 434.



which torrents and rivers descended, carrying down gravel and sand. The plutonic rock or granite (B) may even then have been previously injected at a certain depth below, and yet may never have been exposed to denudation.

As to the time and manner of the subsequent protrusion of the coarse-grained granite No. 2., this rock may have been thrust up bodily, in a solid form, during that long series of igneous operations which produced the trappean and plutonic formations, Nos. 5., 6. *a.*, and 6. *b.*

We have shown that these eruptions, whatever their date, were posterior to the deposition of all the fossiliferous strata of Arran. We can also prove that subsequently both the granitic and trappean rocks underwent great aqueous denudation, which they probably suffered during

their emergence from the sea. The fact is demonstrated by the abrupt truncation of numerous dikes, such as those at *c*, *d*, *e*, which are cut off on the surface of the granite and trap. The overlying trap also ceases very abruptly on approaching the boundary of the great hypogene region, and terminates in a steep escarpment facing towards it as at *f*, Fig. 433. When in its original fluid state it could not have come thus suddenly to an end, but must have filled up the hollow now separating it from the hypogene rocks, had such a hollow then existed. This necessity of supposing that both the trap and the conglomerate once extended farther, and that veins such as *c*, *d*, (Fig. 433.) were once prolonged farther upwards, prepares us to believe that the whole of the northern granite may at one time have been covered by newer formations, under the pressure of which, before its protrusion, it assumed its highly crystalline texture.

The theory of the protrusion in a solid form of the northern nucleus of granite is confirmed by the manner in which the hypogene slates (No. 1.) and the beds of conglomerate (No. 3.) dip away from it on all sides. In some places indeed the slates are inclined towards the granite, but this exception might have been looked for because these hypogene strata have undergone disturbances at more than one geological epoch, and

may at some points, perhaps, have their original order of position inverted. The high inclination, therefore, and the quaquaversal dip of the beds around the borders of the granitic boss, and the comparative horizontality of the fossiliferous strata in the southern part of the island, are facts which all accord with the hypothesis of a great amount of movement at that point where the granite is supposed to have been thrust up bodily, and where we may conceive it to have been distended laterally by the repeated injection of fresh supplies of melted materials.*

* For the geology of Arran consult the works of Drs. Hutton and MacCulloch, the Memoirs of Messrs. Von Dechen and Oeynhausien, that of Professor Sedgwick and Mr. Murchison (Geol. Trans. 2d series), Mr. L. A. Necker's Memoir, read to the Royal Soc. of Edin. 20th April, 1840, and Mr. Ramsay's Geol. of Arran, 1841. I examined myself a large part of Arran in 1836.

CHAPTER XXXIV.

METAMORPHIC ROCKS.

General character of metamorphic rocks—Gneiss—Hornblende-schist—Mica-schist—Clay-slate—Quartzite—Chlorite-schist—Metamorphic limestone—Alphabetical list and explanation of other rocks of this family—Origin of the metamorphic strata—Their stratification is real and distinct from cleavage—On joints and slaty cleavage—Supposed causes of these structures—how far connected with crystalline action.

WE have now considered three distinct classes of rocks; first, the aqueous, or fossiliferous; secondly, the volcanic; and, thirdly, the plutonic, or granitic; and we have now lastly to examine those crystalline (or hypogene) strata to which the name of *metamorphic* has been assigned. The last-mentioned term expresses, as before explained, a theoretical opinion that such [strata, after having been deposited from water, acquired by the influence of heat and other causes a highly crystalline texture.

These rocks, when in their most characteristic or normal state, are wholly devoid of organic remains, and contain no distinct fragments of other rocks whether rounded or angular. They sometimes break out in the central parts of narrow

mountain chains, but in other cases extend over areas of vast dimensions, occupying, for example, nearly the whole of Norway and Sweden, where, as in Brazil, they appear alike in the lower and higher grounds. In Great Britain those members of the series which approach most nearly to granite in their composition, as gneiss, mica-schist, and hornblende-schist, are confined to the country north of the rivers Forth and Clyde.

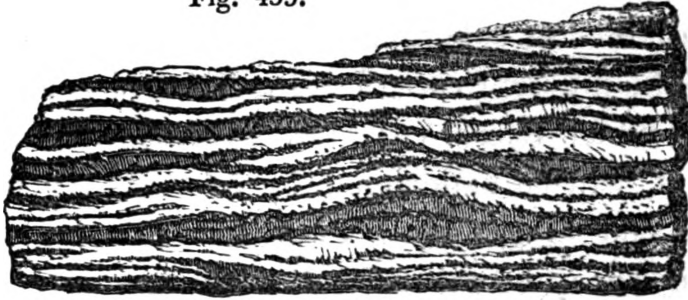
Many attempts have been made to trace a general order of succession or superposition in the members of this family ; gneiss, for example, having been often supposed to hold invariably a lower geological position than mica-schist. But although such an order may prevail throughout limited districts, it is by no means universal, nor even general throughout the globe. To this subject, however, I shall again revert in the last chapter of this volume, when the chronological relations of the metamorphic rocks are pointed out.

The following may be enumerated as the principal members of the metamorphic class,—gneiss, mica-schist, hornblende-schist, clay-slate, chlorite-schist, hypogene or metamorphic limestone, and certain kinds of quartz rock or quartzite.

Gneiss.—The first of these, gneiss, may be called stratified granite, being formed of the same materials as granite, namely felspar, quartz, and mica. In the specimen here figured, the

white layers consist almost exclusively of granular felspar, with here and there a speck of mica and

Fig. 435.



Fragment of gneiss, natural size; section at right angles to planes of stratification.

grain of quartz. The dark layers are composed of grey quartz and black mica, with occasionally a grain of felspar intermixed. The rock splits most easily in the plane of these darker layers, and the surface thus exposed is almost entirely covered with shining spangles of mica. The accompanying quartz, however, greatly predominates in quantity, but the most ready cleavage is determined by the abundance of mica in certain parts of the dark layer.

Instead of these thin laminæ, gneiss is sometimes simply divided into thick beds, in which the mica has only a slight degree of parallelism to the planes of stratification.

The term "gneiss," however, in geology is commonly used in a wider sense to designate a formation in which the above-mentioned rock prevails, but with which any one of the other

metamorphic rocks, and more especially hornblende-schist, may alternate. These other members of the metamorphic series are, in this case, considered as subordinate to the true gneiss.

The different varieties of rock allied to gneiss, into which felspar enters as an essential ingredient, will be understood by referring to what was said of granite. Thus, for example, hornblende may be superadded to mica, quartz, and felspar, forming a syenitic gneiss; or talc may be substituted for mica, constituting talcose gneiss, a rock composed of felspar, quartz, and talc, in distinct crystals or grains (stratified protogine of the French).

Hornblende-schist is usually black, and composed principally of hornblende, with a variable quantity of felspar, and sometimes grains of quartz. When the hornblende and felspar are nearly in equal quantities, and the rock is not slaty, it corresponds in character with the greenstones of the trap family, and has been called "primitive greenstone." It may be termed hornblende rock. Some of these hornblendic masses may really have been volcanic rocks, which have since assumed a more crystalline or metamorphic texture.

Mica-schist, or *micaceous schist*, is, next to gneiss, one of the most abundant rocks of the metamorphic series. It is slaty, essentially composed of mica and quartz, the mica sometimes

appearing to constitute the whole mass. Beds of pure quartz also occur in this formation. In some districts garnets in regular twelve-sided crystals form an integrant part of mica-schist. This rock passes by insensible gradations into clay-slate.

Clay-slate, or Argillaceous schist.—This rock resembles an indurated clay or shale, is for the most part extremely fissile, often affording good roofing slate. It may consist of the ingredients of gneiss, or of an extremely fine mixture of mica and quartz, or talc and quartz. Occasionally it derives a shining and silky lustre from the minute particles of mica or talc which it contains. It varies from greenish or bluish-grey to a lead colour. It may be said of this, more than of any other schist, that it is common to the metamorphic and fossiliferous series, for some clay-slates taken from each division would not be distinguishable by mineralogical characters.

Quartzite, or Quartz rock, is an aggregate of grains of quartz, which are either in minute crystals, or in many cases slightly rounded, occurring in regular strata associated with gneiss or other metamorphic rocks. Compact quartz, like that so frequently found in veins, is also found together with granular quartzite. Both of these alternate with gneiss or mica-schist, or pass into those rocks by the addition of mica, or of felspar and mica.

Chlorite-schist is a green slaty rock in which

chlorite is abundant in foliated plates, usually blended with minute grains of quartz, or sometimes with felspar or mica. Often associated with, and graduating into, gneiss and clay-slate.

Hypogene, or metamorphic limestone. — This rock, commonly called *primary limestone*, is sometimes a thick bedded white crystalline granular marble used in sculpture; but more frequently it occurs in thin beds, forming a foliated schist much resembling in colour and appearance certain varieties of gneiss and mica-schist. It alternates with both these rocks, and in like manner with argillaceous schist. It then usually contains some crystals of mica, and occasionally quartz, felspar, hornblende, and talc. This member of the metamorphic series enters sparingly into the structure of the hypogene districts of Norway, Sweden, and Scotland, but is largely developed in the Alps.

Before offering any further observations on the probable origin of the metamorphic rocks, I subjoin in the form of a glossary, a brief explanation of some of the principal varieties and their synonyms.

ACTINOLITE-SCHIST. A slaty foliated rock, composed chiefly of actinolite, (an emerald-green mineral, allied to hornblende,) with some admixture of felspar, or quartz, or mica.

AMPELITE. Aluminous slate (Brongniart); occurs both in the metamorphic and fossiliferous series.

AMPHIBOLITE. Hornblende rock, which see.

ARGILLACEOUS-SCHIST, or CLAY-SLATE. See p. 383.

ARKOSE. Term used by Brongniart for granular Quartzite, which see.

CHIASTOLITE-SLATE scarcely differs from clay-slate, but includes numerous crystals of Chialstolite ; in considerable thickness in Cumberland. Chialstolite occurs in long slender rhomboidal crystals. For composition, see Table, p. 210.

CHLORITE-SCHIST. A green slaty rock, in which chlorite, a green scaly mineral, is abundant. See p. 383.

CLAY-SLATE, or ARGILLACEOUS-SCHIST. See p. 383.

EURITE and EURITIC PORPHYRY. A base of compact felspar, with grains of laminar felspar, and often mica and other minerals disseminated (Brongniart). M. D'Aubuisson regards eurite as an extremely fine-grained granite, in which felspar predominates, the whole forming an apparently homogeneous rock. Eurite has been already mentioned as a plutonic rock, but occurs also in beds subordinate to gneiss or mica-slate.

GNEISS. A stratified or laminated rock, same composition as granite. See p. 380.

HORNBLENDE ROCK, or AMPHIBOLITE. Composed of hornblende and felspar. The same composition as hornblende-schist, stratified, but not fissile. See p. 207.

HORNBLENDE-SCHIST, or SLATE. Composed chiefly of hornblende, with occasionally some felspar. See p. 382.

HORNBLENDIC or SYENITIC GNEISS. Composed of felspar, quartz, and hornblende.

HYPOGENE LIMESTONE. See p. 384.

MARBLE. See p. 384.

MICA-SCHIST, or MICACEOUS-SCHIST. A slaty rock, composed of mica and quartz in variable proportions. See p. 382.

MICA-SLATE. See MICA-SCHIST, p. 382.

PHYLLADE. D'Aubuisson's term for clay-slate, from *φυλλα*, a heap of leaves.

PRIMARY LIMESTONE. See **HYPOGENE LIMESTONE**, p. 384.

PROTOGINE. See **TALCOSE-GNEISS**, p. 382.; when unstratified it is Talcose-granite.

QUARTZ ROCK, or QUARTZITE. A stratified rock; an aggregate of grains of quartz. See p. 383.

SERPENTINE occurs in both divisions of the hypogene series, as a stratified or unstratified rock; contains much magnesia; is chiefly composed of the mineral called serpentine, mixed with diallage, talc, and steatite. The pure varieties of this rock, called noble serpentine, consist of a hydrated silicate of magnesia, generally of a greenish colour; this base is commonly mixed with oxide of iron.

TALCOSE-GNEISS. Same composition as talcose-granite or protogine, but either stratified or laminated. See p. 382.

TALCOSE-SCHIST consists chiefly of talc, or of talc and quartz, or of talc and felspar, and has a texture something like that of clay-slate.

WHITESTONE. Same as Eurite.

Origin of the Metamorphic Strata.

Having said thus much of the mineral composition of the metamorphic rocks, I may combine what remains to be said of their structure and history with an account of the opinions entertained of their probable origin. At the same time it may be well to forewarn the reader that we are here entering upon ground of controversy, and soon reach the limits where positive induction ends, and beyond which we can only indulge in speculations. It was once a favour-

ite doctrine, and is still maintained by many, that these rocks owe their crystalline texture, their want of all signs of a mechanical origin, or of fossil contents, to a peculiar and nascent condition of the planet at the period of their formation. The arguments in refutation of this hypothesis will be more fully considered when I show, in the last chapter of this volume, to how many different ages the metamorphic formations are referable, and how gneiss, mica-schist, clay-slate, and hypogene limestone (that of Carrara for example), have been formed, not only since the first introduction of organic beings into this planet, but even long after many distinct races of plants and animals had passed away in succession.

The doctrine respecting the crystalline strata, implied in the name metamorphic, may properly be treated of in this place ; and we must first inquire whether these rocks are really entitled to be called stratified in the strict sense of having been originally deposited as sediment from water. The general adoption by geologists of the term stratified, as applied to these rocks, sufficiently attests their division into beds very analogous, at least in form, to ordinary fossiliferous strata. This resemblance is by no means confined to the existence in both of an occasional slaty structure, but extends to every kind of arrangement which is compatible with the absence of fossils, and of sand,

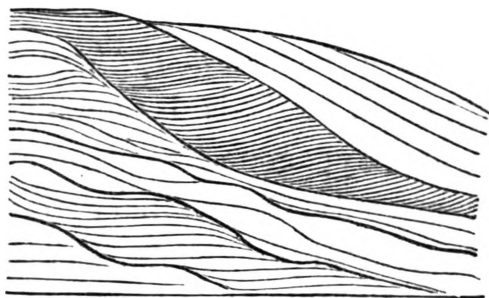
pebbles, ripple-mark, and other characters which the metamorphic theory supposes to have been obliterated by plutonic action. Thus, for example, we behold alike in the crystalline and fossiliferous formations an alternation of beds varying greatly in composition, colour, and thickness. We observe, for instance, gneiss alternating with layers of black hornblende-schist, or with granular quartz, or limestone; and the interchange of these different strata may be repeated for an indefinite number of times. In the like manner, mica-schist alternates with chlorite-schist, and with granular limestone in thin layers.

As in fossiliferous formations strata of pure siliceous sand alternate with micaceous sand and with layers of clay, so in the crystalline or metamorphic rocks we have beds of pure quartzite alternating with mica-schist and clay-slate. As in the secondary and tertiary series we meet with limestone alternating again and again with micaceous or argillaceous sand, so we find in the hypogene, gneiss and mica-schist alternating with pure and impure granular limestones.

It has also been shown that the ripple-mark is very commonly repeated throughout a considerable thickness of fossiliferous strata; so in mica-schist and gneiss, there is sometimes an undulation of the laminæ on a minute scale, which may, perhaps, be a modification of similar inequalities in the original deposit.

In the crystalline formations also, as in many of the sedimentary before described, single strata are sometimes made up of laminæ placed diagonally, such laminæ not being regularly parallel to the planes of cleavage.

This disposition of the layers is illustrated in the accompanying diagram, in which I have re-
Fig. 436.



*Lamination of clay-slate, Montagne de Seguinat, near Gavarnie,
in the Pyrenees.*

presented carefully the stratification of a coarse argillaceous schist, which I examined in the Pyrenees, part of which approaches in character to a green and blue roofing slate, while part is extremely quartzose, the whole mass passing downwards into micaceous schist. The vertical section here exhibited is about three feet in height, and the layers are sometimes so thin that fifty may be counted in the thickness of an inch. Some of them consist of pure quartz.

The inference drawn from the phenomena above described, in favour of the aqueous origin of clay-slate and other crystalline strata, is greatly

strengthened by the fact that many of these metamorphic rocks occasionally alternate with, and sometimes pass by intermediate gradations into, rocks of a decidedly mechanical origin, and exhibiting traces of organic remains. The fossiliferous formations, moreover, into which this passage is effected, are by no means invariably of the same age nor of the highest antiquity, as will be afterwards explained.

Stratification of the metamorphic rocks distinct from cleavage.—The beds into which gneiss, mica-schist, and hypogene limestone divide, exhibit most commonly, like ordinary strata, a want of perfect geometrical parallelism. For this reason, therefore, in addition to the alternate recurrence of layers of distinct materials, the stratified arrangement of the crystalline rocks cannot be explained away by supposing it to be simply a divisional structure like that to which we owe some of the slates used for writing and roofing. *Slaty cleavage*, as it has been called, has in many cases been produced by the regular deposition of thin plates of fine sediment one upon another ; but there are many instances where it is decidedly unconnected with such a mode of origin, and where it is not even confined to the aqueous formations. Some kinds of trap, for example, as clinkstone, split into laminæ, and are used for roofing.

There are, says Professor Sedgwick, three dis-

tingent forms of structure exhibited in certain rocks throughout large districts : viz.—First, stratification ; secondly, joints ; and thirdly, slaty cleavage ; the two last having no connection with true bedding, and having been superinduced by causes absolutely independent of gravitation. All these different structures must have different names, even though there be some cases where it is impossible, after carefully studying the appearances, to decide upon the class to which they belong.*

Joints.—Now, in regard to the second of these forms of structure or joints, they are natural fissures which often traverse rocks in straight and well-determined lines. They afford to the quarryman, as Mr. Murchison observes, when speaking of the phenomena, as exhibited in Shropshire and the neighbouring counties, the greatest aid in the extraction of blocks of stone ; and, if a sufficient number cross each other, the whole mass of rock is split into symmetrical blocks.† The faces of the joints are for the most part smoother and more regular than the surfaces of true strata. The joints are straight-cut chinks, often slightly open, often passing, not only through layers of successive deposition, but also through balls of limestone or other matter which have been formed

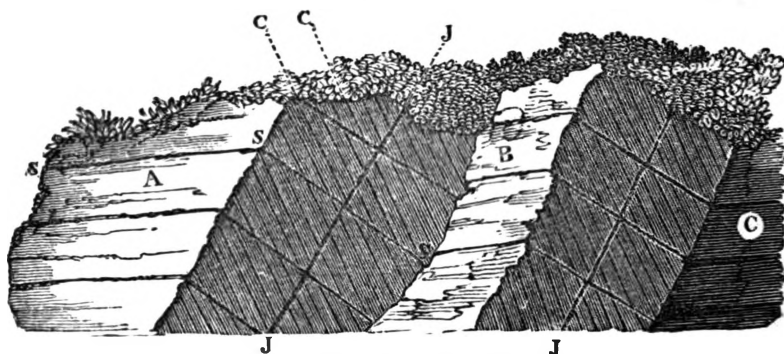
* Geol. Trans., Second Series, vol. iii. p. 480.

† The Silurian System of Rocks, as developed in Salop, Hereford, &c., p. 245.

by concretionary action, since the original accumulation of the strata. Such joints, therefore, must often have resulted from one of the last changes superinduced upon sedimentary deposits.*

In the annexed diagram the flat surfaces of rock A, B, C, represent exposed faces of joints, to which the walls of other joints, J J, are parallel. S S are the lines of stratification; C C are lines of slaty cleavage which intersect the rock at a considerable angle to the planes of stratification.

Fig. 437.

*Stratification, joints, and cleavage.*

Joints, according to Professor Sedgwick, are distinguishable from lines of slaty cleavage in this, that the rock intervening between two joints has no tendency to cleave in a direction parallel to the planes of the joints, whereas a rock is capable of indefinite subdivision in the direction of its slaty cleavage. In some cases where the strata

* The Silurian System of Rocks, as developed in Salop, Hereford, &c., p. 246.

are curved, the planes of cleavage are still perfectly parallel. This has been observed in the slate rocks of part of Wales (see Fig. 438.), which

Fig. 438.



Parrallel planes of cleavage intersecting curved strata. (Sedgwick)

consist of a hard greenish slate. The true bedding is there indicated by a number of parallel stripes, some of a lighter and some of a darker colour than the general mass. Such stripes are found to be parallel to the true planes of stratification, wherever these are manifested by ripple-mark, or by beds containing peculiar organic remains. Some of the contorted strata are of a coarse mechanical structure, alternating with fine-grained crystalline chloritic slates, in which case the same slaty cleavage extends through the coarser and finer beds, though it is brought out in greater perfection in proportion as the materials of the rock are fine and homogeneous. It is only when these are very coarse that the cleavage planes entirely vanish. These planes are usually inclined at a very considerable angle to the planes of the strata. In the Welsh chains, for example, the average angle is as much as from 30° to 40° . Sometimes the cleavage planes dip towards the same point of the compass as those of stratification, but

more frequently to opposite points. It may be stated as a general rule, that when beds of coarser materials alternate with those composed of finer particles, the slaty cleavage is either entirely confined to the fine-grained rock, or is very imperfectly exhibited in that of coarser texture. This rule holds, whether the cleavage is parallel to the planes of stratification or not.

In the Swiss and Savoy Alps, as Mr. Bakewell has remarked, enormous masses of limestone are cut through so regularly by nearly vertical partings, and these are often so much more conspicuous than the seams of stratification, that an unexperienced observer will almost inevitably confound them, and suppose the strata to be perpendicular in places where in fact they are almost horizontal.*

Now these joints are supposed to be analogous to those partings which have been already observed to separate volcanic and plutonic rocks into cuboidal and prismatic masses. On a small scale we see clay and starch when dry split into similar shapes, which is often caused by simple contraction, whether the shrinking be due to the evaporation of water, or to a change of temperature. It is well known that many sandstones and other rocks expand by the application of mo-

* Introduction to Geology, chap. iv.

derate degrees of heat, and then contract again on cooling ; and there can be no doubt that large portions of the earth's crust have, in the course of past ages, been subjected again and again to very different degrees of heat and cold. These alternations of temperature have probably contributed largely to the production of joints in rocks.

In some countries, as in Saxony, where masses of basalt rest on sandstone, the aqueous rock has for the distance of several feet from the point of junction assumed a columnar structure similar to that of the trap. In like manner some hearth-stones, after exposure to the heat of a furnace without being melted, have become prismatic. Certain crystals also acquire by the application of heat a new internal arrangement, so as to break in a new direction, their external form remaining unaltered.

Scoresby, when speaking of the icebergs of Spitzbergen, states that "they are full of rents, extending perpendicularly downwards, and dividing them into innumerable columns." Colonel Jackson, who has lately investigated this subject more attentively, found that the ice on the Neva, at St. Petersburg, at the beginning of a thaw, when two feet in thickness, is traversed by rows of very minute air-bubbles extending in straight lines, sometimes a little inflected, from the upper circle of the ice towards the

lower, within from two to five inches of which they terminate. "Other blocks presented these bubbles united, so as to form cylindrical canals, a little thicker than a horsehair. Observing still further," he says, "I found blocks in which the process was more advanced, and two, three, or more clefts, struck off in different directions from the vertical veins, so that a section perpendicular to the vein would represent in miniature the star-formed cracks of timber. Finally, in some pieces, these cracks united from top to bottom of the veins, separating the whole mass into vertical prisms, having a greater or less number of sides. In this state a slight shock was sufficient to detach them; and the block with its scattered fragments was in all respects the exact miniature resemblance, in crystal, of a Giant's Causeway. The surface was like a tessellated pavement, and the columns rose close, adhering and parallel, from the compact mass of a few inches at the under surface. More or less time is required for the process, which I have since seen in all its different stages." *

Here again we find the columnar or jointed structure in a solid mass, which had been subjected to great changes of temperature.

It seems, therefore, that the fissures called

* Journ. of Roy. Geograph. Soc., vol. v. p. 19.

joints may have been the result of different causes, as of some modification of crystalline action, or simple contraction during consolidation, or during a change of temperature. And there are cases where joints may have been due to mechanical violence, and the strain exerted on strata during their upheaval, or when they have sunk down below their former level. Professor Phillips has suggested that the previous existence of divisional planes may often have determined, and must greatly have modified, the lines and points of fracture caused in rocks by those forces to which they owe their elevation or dislocations. These lines and points being those of least resistance, cannot fail to have influenced the direction in which the solid mass would give way on the application of external force.

It has been observed by Mr. Murchison, that in referring both joints and slaty cleavage to crystalline action, we are borne out by a well-known analogy in which crystallization has in like manner given rise to two distinct kinds of structure in the same body. Thus, for example, in a six-sided prism of quartz, the planes of cleavage are distinct from those of the prism. It is impossible to cleave the crystals parallel to the plane of the prism, just as slaty rocks cannot be cleaved parallel to the joints; but the quartz

crystal, like the older schists, may be cleaved *ad infinitum* in the direction of the cleavage planes.*

I have already stated that extremely fine slates, like those of the Niesen, near the Lake of Thun, in Switzerland, are perfectly parallel to the planes of stratification, and are, therefore, probably due to successive aqueous deposition. Even when the slates are oblique to the general planes of the strata, it by no means follows as a matter of course that they have been caused by crystalline action, for they may be the result of that diagonal lamination which I have before described (p. 35.). In this case, however, there is usually much irregularity, whereas those cleavage planes oblique to the true stratification, which are referred to a crystalline action, are often perfectly symmetrical, and observe a strict geometrical parallelism, even when the strata are contorted, as already described (p. 393.).

In regard to the origin of slaty cleavage, where it is unconnected with sedimentary deposition, Professor Sedgwick is of opinion that no retreat of parts, no contraction in dimensions, in passing to a solid state, can account for the phenomenon. It must be referred to crystalline or polar forces acting simultaneously and some-

* Silurian System of Rocks, &c., p. 246.

what uniformly, in given directions, on large masses having a homogeneous composition.

A fact recorded by Mr. Darwin affords confirmation to this theory. The ore of the gold mines of Yaquil, in Chili, is ground in a mill into an impalpable powder. After this powder has been washed, and nearly all the metal separated, the mud which passes from the mills is collected into pools, where it subsides, and is cleared out and thrown into a common heap. A great deal of chemical action then commences, salts of various kinds effloresce on the surface, and the mass becomes hard, and divides into concretionary fragments. These fragments were observed to possess *an even and well-defined slaty structure*; but the laminæ were not inclined at any uniform angle.*

Mr. R. W. Fox lately submitted a mass of moist clay, worked up with acidulated water, to weak voltaic action for some months, and it was found when dry to be rudely laminated, the planes of the slightly undulating laminæ being at right angles to the direction of the electrical forces.†

Sir John Herschel, in allusion to slaty cleav-

* Journal of Travels in S. America. &c., p. 234.

† Although the lamination in the specimen shown to me was very imperfect, it was sufficiently evident to encourage farther experiments.

age, has suggested, "that if rocks have been so heated as to allow a commencement of crystallization; that is to say, if they have been heated to a point at which the particles can begin to move amongst themselves, or at least on their own axes, some general law must then determine the position in which these particles will rest on cooling. Probably that position will have some relation to the direction in which the heat escapes. Now, when all, or a majority of particles of the same nature, have a general tendency to one position, that must of course determine a cleavage plane. Thus we see the infinitesimal crystals of fresh precipitated sulphate of barytes, and some other such bodies, arrange themselves alike in the fluid in which they float; so as, when stirred, all to glance with one light, and give the appearance of silky filaments. Some sorts of soap, in which insoluble margarates* exist, exhibit the same phenomenon when mixed with water; and what occurs in our experiments on a minute scale may occur in nature on a great one."†

* Margaric acid is an oleaginous acid, formed from different animal and vegetable fatty substances. A margarate is a compound of this acid with soda, potash, or some other base, and is so named from its pearly lustre.

† Letter to the author, dated Cape of Good Hope, Feb. 20. 1836.

CHAPTER XXXV.

METAMORPHIC ROCKS — *continued.*

Strata near some intrusive masses of granite converted into rocks identical with different members of the metamorphic series — Arguments hence derived as to the nature of plutonic action — Time may enable this action to pervade denser masses — From what kinds of sedimentary rock each variety of the metamorphic class may be derived — Certain objections to the metamorphic theory considered.

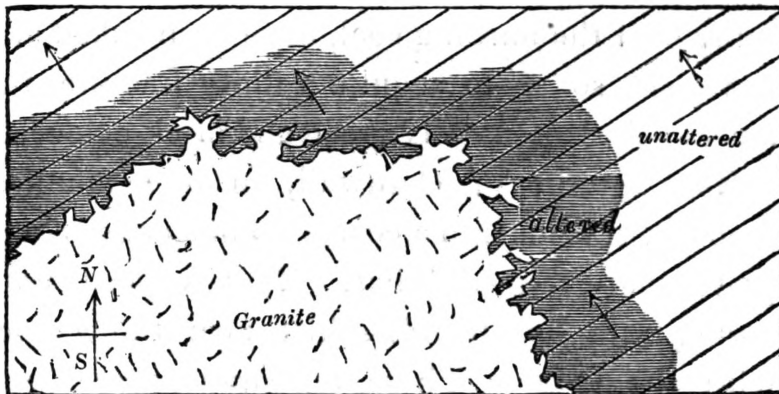
It has been seen that geologists have been very generally led to infer, from the phenomena of joints and slaty cleavage, that mountain masses, of which the sedimentary origin is unquestionable, have been acted upon simultaneously by vast crystalline forces. That the structure of fossiliferous strata has often been modified by some general cause since their original deposition, and even subsequently to their consolidation and dislocation, is undeniable. These facts prepare us to believe that still greater changes may have been worked out by a greater intensity, or more prolonged development of the same agency, combined, perhaps, with other causes. Now we have seen that, near the immediate contact of granitic veins and volcanic dikes, very extraordinary alterations in rocks have taken place,

more especially in the neighbourhood of granite. It will be useful here to add other illustrations, showing that a texture undistinguishable from that which characterizes the more crystalline metamorphic formations, has actually been superinduced in strata once fossiliferous.

In the southern extremity of Norway there is a large district, on the west side of the fiord of Christiania, in which granite or syenite protrudes in mountain masses through fossiliferous strata, and usually sends veins into them at the point of contact. The stratified rocks, replete with shells and zoophytes, consist chiefly of shale, limestone, and some sandstone, and all these are invariably altered near the granite for a distance of from 50 to 400 yards. The aluminous shales are hardened and have become flinty. Sometimes they resemble jasper. Ribboned jasper is produced by the hardening of alternate layers of green and chocolate-coloured schists, each stripe faithfully representing the original lines of stratification. Nearer the granite the schist often contains crystals of hornblende, which are even met with in some places for a distance of several hundred yards from the junction; and this black hornblende is so abundant, that eminent geologists, when passing through the country, have confounded it with the ancient hornblende-schist, subordinate to the great gneiss formation of

Norway. Frequently, between the granite and the hornblende slate, above mentioned, grains of mica and crystalline felspar appear in the schist, so that rocks resembling gneiss and mica-schist are produced. Fossils can rarely be detected in these schists, and they are more completely effaced in proportion to the more crystalline texture of the beds, and their vicinity to the granite. In some places the siliceous matter of the schist becomes a granular quartz ; and when hornblende and mica are added, the altered rock loses its stratification, and passes into a kind of granite. The limestone, which at points remote from the granite is of an earthy texture, blue colour, and often abounds in corals, becomes a white granular

Fig. 439.



Altered zone of fossiliferous slate and limestone near granite. Christiania.

The arrows indicate the dip, and the straight lines the strike, of the beds.

marble near the granite, sometimes siliceous, the granular structure extending occasionally up-

wards of 400 yards from the junction ; and the corals being for the most part obliterated, though sometimes preserved, even in the white marble. Both the altered limestone and hardened slate contain garnets in many places, also ores of iron, lead, and copper, with some silver. These alterations occur equally, whether the granite invades the strata in a line parallel to the general strike of the fossiliferous beds, or in a line at right angles to their strike, as will be seen by the accompanying ground plan.*

The indurated and ribboned schists above mentioned bear a strong resemblance to certain shales of the coal found at Russell's Hall, near Dudley, where coal mines have been on fire for ages. Beds of shale of considerable thickness, lying over the burning coal, have been baked and hardened so as to acquire a flinty fracture, the layers being alternately green and brick-coloured.

The granite of Cornwall, in like manner, sends forth veins into a coarse argillaceous-schist, provincially termed killas. This killas is converted into hornblende-schist near the contact with the veins. These appearances are well seen at the junction of the granite and killas, in St. Michael's Mount, a small island nearly 300 feet high, situated in the bay, at a distance of about three miles from Penzance.

* Keilhau, *Gæa Norvegica*, pp. 61–63.

The granite of Dartmoor, in Devonshire, says Mr. De la Beche, has intruded itself into the slate and slaty sandstone called greywacké, twisting and contorting the strata, and sending veins into them. Hence some of the slate rocks have become "micaceous; others more indurated, and with the characters of mica-slate, and gneiss; while others again appear converted into a hard-zoned rock strongly impregnated with felspar." *

We learn from the investigations of M. Dufrénoy, that in the eastern Pyrenees there are mountain masses of granite posterior in date to the formations called lias and chalk of that district, and that these fossiliferous rocks are greatly altered in texture, and often charged with iron-ore, in the neighbourhood of the granite. Thus in the environs of St. Martin, near St. Paul de Fénouillet, the chalky limestone becomes more crystalline and saccharoid as it approaches the granite, and loses all trace of the fossils which it previously contained in abundance. At some points, also, it becomes dolomitic, and filled with small veins of carbonate of iron, and spots of red iron-ore. At Rancié the lias nearest the granite is not only filled with iron-ore, but charged with pyrites, tremolite, garnet, and a new mineral somewhat

* Geol. Manual, p. 479.

allied to felspar, called, from the place in the Pyrenees where it occurs, "couzeranite."

Now the alterations above described as super-induced in rocks by volcanic dikes and granite veins, prove incontestably that powers exist in nature capable of transforming fossiliferous into crystalline strata,—powers capable of generating in them a new mineral character, similar, nay, often absolutely identical with that of gneiss, mica-schist, and other stratified members of the hypogene series. The precise nature of these altering causes, which may provisionally be termed plutonic, is in a great degree obscure and doubtful ; but their reality is no less clear, and we must suppose the influence of heat to be in some way connected with the transmutation, if, for reasons before explained, we concede the igneous origin of granite.

The experiments of Gregory Watt, in fusing rocks in the laboratory, and allowing them to consolidate by slow cooling, prove distinctly that a rock need not be perfectly melted in order that a re-arrangement of its component particles should take place, and a partial crystallization ensue.* We may easily suppose, therefore, that all traces of shells and other organic remains may be destroyed ; and that new chemical combinations

* Phil. Trans. 1804.

may arise, without the mass being so fused as that the lines of stratification should be wholly obliterated.

We must not, however, imagine that heat alone, such as may be applied to a stone in the open air, can constitute all that is comprised in plutonic action. We know that volcanos in eruption not only emit fluid lava, but give off steam and other heated gases, which rush out in enormous volume, for days, weeks, or years continuously, and are oven disengaged from lava during its consolidation. When the materials of granite, therefore, came in contact with the fossiliferous stratum in the bowels of the earth under great pressure, the contained gases might be unable to escape ; yet when brought into contact with rocks, might pass through their pores with greater facility than water is known to do. (See vol. i. p. 76.) These aeriform fluids, such as sulphuretted hydrogen, muriatic acid, and carbonic acid, issue in many places from rents in rocks, which they have discoloured and corroded, softening some and hardening others. If the rocks are charged with water, they would pass through more readily ; for, according to the experiments of Henry, water, under an hydrostatic pressure of ninety-six feet, will absorb three times as much carbonic acid gas as it can under the ordinary pressure of the atmosphere. Although this increased power of absorption would be diminished, in consequence of the

higher temperature found to exist as we descend in the earth, yet Professor Bischoff has shown that the heat by no means augments in such a proportion as to counteract the effect of augmented pressure.* There are other gases, as well as the carbonic acid, which water absorbs, and more rapidly in proportion to the amount of pressure. Now even the most compact rocks may be regarded, before they have been exposed to the air and dried, in the light of sponges filled with water; and it is conceivable that heated gases brought into contact with them, at great depths, may be absorbed readily, and transfused through their pores. Although the gaseous matter first observed would soon be condensed, and part with its heat, yet the continual arrival of fresh supplies from below might, in the course of ages, cause the temperature of the water, and with it that of the containing rock, to be materially raised.

M. Fournet, in his description of the metalliferous gneiss near Clermont, in Auvergne, states that all the minute fissures of the rock are quite saturated with free carbonic acid gas, which rises plentifully from the soil there and in many parts of the surrounding country. The various elements of the gneiss, with the exception of the quartz, are all softened; and new combinations of the

* Poggendorf's *Annalen*, No. XVI. Second Series, vol. iii.

acid, with lime, iron, and manganese, are continually in progress.*

Another illustration of the power of subterranean gases is afforded by the stufas of St. Calogero, situated in the largest of the Lipari Islands. Here, according to the description published by Hoffmann, horizontal strata of tuff, extending for four miles along the coast, and forming cliffs more than 200 feet high, have been discoloured in various places, and strangely altered by the "all-penetrating vapours." Dark clays have become yellow, or often snow-white; or have assumed a chequered and brecciated appearance, being crossed with ferruginous red stripes. In some places the fumeroles have been found by analysis to consist partly of sublimations of oxide of iron; but it also appears that veins of calcedony and opal, and others of fibrous gypsum, have resulted from these volcanic exhalations.†

The reader may also refer to M. Virlet's account of the corrosion of hard, flinty, and jaspideous rocks near Corinth, by the prolonged agency of subterranean gases‡; and to Dr. Daubeny's description of the decomposition of trachytic rocks

* See Principles, *Index*, "Carbonated Springs," &c.

† Hoffmann's *Liparischen Inseln*, p. 38. Leipzig, 1832.

‡ See *Princ. of Geol.*; and *Bulletin de la Soc. Géol. de France*, tom. ii. p. 330.

in the Solfatara, near Naples, by sulphuretted hydrogen and muriatic acid gases.*

Although in all these instances we can only study the phenomena as exhibited at the surface, it is clear that the gaseous fluids must have made their way through the whole thickness of porous or fissured rocks, which intervene between the subterranean reservoirs of gas and the external air. The extent, therefore, of the earth's crust, which the vapours have permeated and are now permeating, may be thousands of fathoms in thickness, and their heating and modifying influence may be spread throughout the whole of this solid mass.

We learn from Professor Bischoff that the steam of a hot spring at Aix-la-Chapelle, although its temperature is only from 133° to 167° F., has converted the surface of some blocks of black marble into a doughy mass. He conceives, therefore, that steam in the bowels of the earth having a temperature equal or even greater than the melting point of lava, and having an elasticity of which even Papin's digester can give but a faint idea, may convert rocks into melted liquid matter.†

The above observations are calculated to meet some of the objections which have been urged

* See Princ. of Geol.; and Daubeny's Volcanos, p. 167.

† Jam. Ed. New Phil. Journ., No. 51. p. 43.

against the metamorphic theory on the ground of the small power of rocks to conduct heat ; for it is well known that rocks, when dry and in the air, differ remarkably from metals in this respect. It has been asked how the changes which extend merely for a few feet from the contact of a dike could have penetrated through mountain masses of crystalline strata several miles in thickness. Now it has been stated that the plutonic influence of the syenite of Norway, has sometimes altered fossiliferous strata for a distance of a quarter of a mile, both in the direction of their dip and of their strike. (See Fig. 439. p. 403.) This is undoubtedly an extreme case ; but is it not far more philosophical to suppose that this influence may, under favourable circumstances, affect denser masses, than to invent an entirely new cause to account for effects merely differing in quantity, and not in kind ? The metamorphic theory does not require us to affirm that some contiguous mass of granite has been the altering power ; but merely that an action, existing in the interior of the earth at an unknown depth, whether thermal, electrical, or other, analogous to that exerted near intruding masses of granite, has, in the course of vast and indefinite periods, and when rising perhaps from a large heated surface, reduced strata thousands of yards thick to a state of semi-fusion, so that

on cooling they have become crystalline, like gneiss. Granite may have been another result of the same action in a higher state of intensity, by which a thorough fusion has been produced ; and in this manner the passage from granite into gneiss may be explained.

Some geologists are of opinion, that the alternate layers of mica and quartz, or mica and felspar, or lime and felspar, are so much more distinct in certain metamorphic rocks, than the ingredients composing alternate layers in many sedimentary deposits, that the similar particles must be supposed to have exerted a molecular attraction for each other, and to have thus congregated together in layers, more distinct in mineral composition than before they were crystallized.

In considering, then, the various data already enumerated, the forms of stratification in metamorphic rocks, their passage on the one hand into the fossiliferous, and on the other into the plutonic formations, and the conversions which can be ascertained to have occurred in the vicinity of granite, we may conclude that gneiss and mica-schist may be nothing more than altered micaceous and argillaceous sandstones, that granular quartz may have been derived from siliceous sandstone, and compact quartz from the same materials. Clay-slate may be altered shale, and granular marble may have originated in the form of ordi-

nary limestone, replete with shells and corals, which have since been obliterated ; and, lastly, calcareous sands and marls may have been changed into impure crystalline limestones.

“Hornblende-schist,” says Dr. MacCulloch, “may at first have been mere clay ; for clay or shale is found altered by trap into Lydian stone, a substance differing from hornblende-schist almost solely in compactness and uniformity of texture.” * “In Shetland,” remarks the same author, “argillaceous-schist (or clay-slate), when in contact with granite, is sometimes converted into hornblende-schist, the schist becoming first siliceous, and ultimately, at the contact, hornblende-schist.” †

The anthracite found associated with hypogene rocks may have been coal ; for we know that, in the vicinity of some trap dikes, coal is converted into anthracite.

The total absence of any trace of fossils has inclined many geologists to attribute the origin of crystalline strata to a period antecedent to the existence of organic beings. Admitting, they say, the obliteration, in some cases, of fossils by plutonic action, we might still expect that traces of them would oftener occur in certain ancient systems of slate, in which, as in Cumberland, some

* Syst. of Geol., vol. i. p. 210.

† Ibid., p. 211.

conglomerates occur. But in urging this argument, it seems to have been forgotten, that there are stratified formations of enormous thickness, and of various ages, and some of them very modern, all formed after the earth had become the abode of living creatures, which are nevertheless in certain districts entirely destitute of all vestiges of organic bodies. In some, the traces of fossils may have been effaced by water and acids, at many successive periods ; and it is clear, that the older the stratum, the greater is the chance of its being non-fossiliferous, even if it has escaped all metamorphic action.

It has been also objected to the metamorphic theory, that the chemical composition of the secondary strata differs essentially from that of the crystalline schists, into which they are supposed to be convertible.* The "primary" schists, it is said, usually contain a considerable proportion of potash or of soda, which the secondary clays, shales, and slates do not, these last being the result of the decomposition of felspathic rocks, from which the alkaline matter has been abstracted during the process of decomposition. But this reasoning proceeds on insufficient and apparently mistaken data ; for a large portion of what is usually called clay, marl, shale, and slate does

* Dr. Boase, *Primary Geology*, p. 319.

actually contain a certain and often a considerable proportion of alkali ; so that it is difficult in many countries to obtain clay or shale sufficiently free from alkaline ingredients to allow of their being burnt into bricks or used for pottery.

Thus the argillaceous shales, as they are called, and slates of the Old Red sandstone, in Forfarshire and other parts of Scotland, are so much charged with alkali, derived from triturated felspar, that, instead of hardening when exposed to fire, they sometimes melt into a glass. They contain no lime, but appear to consist of extremely minute grains of the various ingredients of granite, which are distinctly visible in the coarser-grained varieties, and in almost all the interposed sandstones. These laminated clays, marls, and shales might certainly, if crystallized, resemble in composition many of the primary strata.

There is also potash in the vegetable remains included in strata, and soda in the salt by which they are sometimes so largely impregnated, as in Patagonia.

Another objection has been derived from the alternation of highly crystalline strata with others having a less crystalline texture. The heat, it is said, in its ascent from below, must have traversed the less altered schists before it reached a higher and more crystalline bed. In answer to this, it may be observed, that if a number of strata differ-

ing greatly in composition from each other be subjected to equal quantities of heat, there is every probability that some will be more fusible than others. Some, for example, will contain soda, potash, lime, or some other ingredient capable of acting as a flux ; while others may be destitute of the same elements, and so refractory as to be very slightly affected by a degree of heat capable of reducing others to semi-fusion. Nor should it be forgotten that, as a general rule, the less crystalline rocks do really occur in the upper, and the more crystalline in the lower part of each metamorphic series.

But it will be impossible for the reader duly to appreciate the propriety of the term metamorphic, as applied to the strata hitherto called primary, until I have shown in the next chapter, that these crystalline strata have been formed at a great variety of distinct periods.

CHAPTER XXXVI.

ON THE DIFFERENT AGES OF THE METAMORPHIC ROCKS.

Age of each set of metamorphic strata twofold — Test of age by fossils and mineral character not available — Test by superposition ambiguous — Conversion of dense masses of fossiliferous strata into metamorphic rocks — Limestone and shale of Carrara — Metamorphic strata of modern periods in the Alps of Switzerland and Savoy — Why the visible crystalline strata are none of them very modern — Order of succession in metamorphic rocks — Uniformity of mineral character — Why the metamorphic strata are less calcareous than the fossiliferous — Concluding remarks.

ACCORDING to the theory adopted in the last chapter, the age of each set of metamorphic strata is twofold, they have been deposited at one period, they have become crystalline at another. We can rarely hope to define with exactness the date of both these periods, the fossils having been destroyed by plutonic action, and the mineral characters being the same, whatever the age. Superposition itself is an ambiguous test, especially when we desire to determine the period of crystallization. Suppose, for example, we are convinced that certain metamorphic strata in the

Alps, which are covered by cretaceous beds, are altered lias; this lias may have assumed its crystalline texture in the cretaceous or in some tertiary period, the Eocene for example. If in the latter, it should be called Eocene, when regarded as a metamorphic rock, although it be liassic, when considered in reference to the era of its deposition. According to this view, the superposition of chalk does not prevent the subjacent *metamorphic* rock from being Eocene. If, however, in the progress of science, we should succeed in ascertaining the twofold chronological relations of the metamorphic formations, it might be useful to adopt a twofold terminology. We might call the strata above alluded to Liassic-Eocene, or Liassic-Cretaceous; the first term referring to the era of deposition, the second to that of crystallization. According to this method, the chlorite-schist, mica-schist, and gneiss of the Malvern Hills, would belong to the Silurian-Old Red sandstone period, because they are Silurian strata altered into metamorphic rocks during the deposition of the Old Red sandstone. (See. p. 365.)

We have seen, when discussing the ages of the plutonic rocks, that examples occur of various primary, secondary, and tertiary deposits converted into metamorphic strata, near their contact with granite. There can be no doubt in these cases that strata, once composed of mud, sand,

and gravel, or of clay, marl, and shelly limestone, have for the distance of several yards, and in some instances several hundred feet, been turned into gneiss, mica-schist, hornblende-schist, chlorite-schist, quartz rock, statuary marble, and the rest. (See the two preceding Chapters.)

But when the metamorphic action has operated on a grander scale, it tends entirely to destroy all monuments of the date of its development. It may be easy to prove the identity of two different parts of the same stratum; one, where the rock has been in contact with a volcanic or plutonic mass, and has been changed into marble or hornblende-schist, and another not far distant, where the same bed remains unaltered and fossiliferous; but when we have to compare two portions of a mountain chain — the one metamorphic, and the other unaltered — all the labour and skill of the most practised observers are required. I shall mention one or two examples of alteration on a grand scale, in order to explain to the student the kind of reasoning by which we are led to infer that dense masses of fossiliferous strata have been converted into crystalline rocks.

Northern Apennines. — Carrara. — The celebrated marble of Carrara, used in sculpture, was once regarded as a type of primitive limestone. It abounds in the mountains of Massa Carrara, or the “Apuan Alps,” as they have been called, the

highest peaks of which are nearly 6000 feet high. Its great antiquity was inferred from its mineral texture, from the absence of fossils, and its passage downwards into talc-schist and garnetiferous mica-schists; these rocks again graduating downwards into gneiss, which is penetrated, at Forno, by granite veins. Now the researches of MM. Savi, Boué, Pareto, Guidoni, De la Beche, and especially Hoffmann, have demonstrated that this marble, once supposed to be formed before the existence of organic beings, is, in fact, an altered limestone of the Oolitic period, and the underlying crystalline schists are secondary sandstones and shales, modified by plutonic action. In order to establish these conclusions it was first pointed out, that the calcareous rocks bordering the Gulf of Spezia, and abounding in Oolitic fossils, assume a texture like that of Carrara marble, in proportion as they are more and more invaded by certain trappean and plutonic rocks, such as diorite, euphotide, serpentine, and granite, occurring in the same country.

It was then observed that, in places where the secondary formations are unaltered, the uppermost consist of common Apennine limestone with nodules of flint, below which are shales, and at the base of all, argillaceous and siliceous sandstones. In the limestone, fossils are frequent, but very rare in the underlying shale and sandstone.

Now a gradation has been traced laterally from these rocks into another and corresponding series, which is completely metamorphic; for at the top of this we find a white granular marble, wholly devoid of fossils, and almost without stratification, in which there are no nodules of flint, but in its place siliceous matter disseminated through the mass in the form of prisms of quartz. Below this, and in place of the shales, are talc-schists, jasper, and hornstone; and at the bottom, instead of the siliceous and argillaceous sandstones, are quartzite and gneiss.* Had these secondary strata of the Apennines undergone universally as great an amount of transmutation, it would have been impossible to form a conjecture respecting their true age; and then, according to the common method of geological classification, they would have ranked as primary rocks. In that case the date of their origin would have been thrown back to an era antecedent to the deposition of the Lower Cambrian strata, although in reality they were formed in the Oolitic period, and altered at some subsequent and unknown epoch.

Alps of Switzerland.—In the Alps, analogous conclusions have been drawn respecting the alteration of strata on a still more extended scale.

* See notices of Savi, Hoffmann, and others, referred to by Boué, *Bull. de la Soc. Géol. de France*, tom. v. p. 317; and tom. iii. p. xlv.

In the eastern part of that chain, some of the primary fossiliferous strata, as well as the older secondary formations, together with the oolitic and cretaceous rocks, are distinctly recognizable. Tertiary deposits also appear in a less elevated position on the flanks of the Eastern Alps; but in the Central or Swiss Alps, the primary fossiliferous, and older secondary formations disappear, and the Cretaceous, Oolitic, and Liassic strata graduate insensibly into metamorphic rocks, consisting of granular limestone, talc-schist, talcose-gneiss, micaceous schist, and other varieties. In regard to the age of this vast assemblage of crystalline strata, we can merely affirm that some of the upper portions are altered newer secondary deposits: but we cannot avoid suspecting that the disappearance both of the older secondary and primary fossiliferous rocks may be owing to their having been all converted in this region into crystalline schist.

It is difficult to convey to those who have never visited the Alps a just idea of the various proofs which concur to produce this conviction. In the first place, there are certain points where strata of the Oolite, Lias, and Chalk have been turned into granular marble, gneiss, and other metamorphic schists, near their contact with granite. This fact shows undeniably that plutonic causes continued to be in operation in the Alps down to a late

period, even after the deposition of some of the newer secondary formations. Having established this point, we are the more willing to believe that many inferior fossiliferous rocks, probably exposed for longer periods to a similar action, may have become metamorphic to a still greater extent.

We also discover in parts of the Swiss Alps dense masses of strata of the age of the Greensand and Chalk, which has assumed that semi-crystalline texture which Werner called transition, and which naturally led his followers, who attached great importance to mineral characters taken alone, to class them as transition formations, or as groups older than the lowest secondary rocks. (See Vol. I. p. 187.) Now, it is probable that these strata have been affected, although in a less intense degree, by that same plutonic action which has entirely altered and rendered metamorphic so many of the subjacent formations ; for in the Alps, this action has by no means been confined to the immediate vicinity of granite. Granite, indeed, and other plutonic rocks rarely make their appearance at the surface, notwithstanding the deep ravines which lay open to view the internal structure of these mountains. That they exist below at no great depth we cannot doubt, and we have already seen (p. 341) that at some points, as in the Valorsine, near Mont Blanc, granite and granitic veins are

observable, piercing through talcose gneiss, which passes insensibly upwards into secondary strata.

It is certainly in the Alps of Switzerland and Savoy, more than in any other district in Europe, that the geologist is prepared to meet with the signs of an intense development of plutonic action; for here we find the most stupendous monuments of mechanical violence, by which strata thousands of feet thick have been bent, folded, and overturned. (See Vol. I. p. 124.) It is here that marine secondary formations of a comparatively modern date, such as the Oolitic and Cretaceous, have been upheaved to the height of 10,000, or even 12,000 feet above the level of the sea; and even tertiary strata, apparently of the Miocene era, have been raised to an elevation of 4000 or 5000 feet, so as to rival in height the loftiest mountains in Great Britain.

If the reader will consult the works of many eminent geologists who have explored the Alps, especially those of MM. De Beaumont, Studer, Necker, and Boué, he will learn that they all share more or less fully, in the opinions above expressed. It has, indeed, been stated by MM. Studer and Hugi, that there are complete alternations on a large scale of secondary strata, containing fossils, with gneiss and other rocks, of a perfectly metamorphic structure. I have visited some of the most remarkable localities referred to by these authors; but, although agreeing

with them that there are passages from the fossiliferous to the metamorphic series far from the contact of granite or other plutonic rocks, I was unable to convince myself that the distinct alternations of highly crystalline, with unaltered strata above alluded to, might not admit of a different explanation. In one of the sections described by M. Studer in the highest of the Bernese Alps, namely in the Roththal, a valley bordering the line of perpetual snow on the northern side of the Jungfrau, I observed a mass of gneiss 1000 feet thick, and 15,000 feet long, not only resting upon, but also again covered by strata containing oolitic fossils. These anomalous appearances may partly be explained by supposing great solid wedges of intrusive gneiss to have been forced in laterally between strata to which I found them to be in many sections unconformable. The superposition, also, of the gneiss to the oolite may, in some cases, be due to a reversal of the original position of the beds in a region where the convulsions have been on so stupendous a scale.

On the Sattel also, at the base of the Gestelhorn, above Enzen, in the valley of Urbach, near Meyringen, some of the intercalations of gneiss between fossiliferous strata may, I conceive, be ascribed to mechanical derangement. Almost any hypothesis of repeated changes of

position may be resorted to in a region of such extraordinary confusion. The secondary strata may first have been vertical, and then certain portions may have become metamorphic (the plutonic influence ascending from below) while intervening strata remained unchanged. The whole series of beds may then again have been thrown into a nearly horizontal position, giving rise to the superposition of crystalline upon fossiliferous formations.

It was remarked, in the 33d chapter, that as the hypogene rocks, both stratified and unstratified, crystallize originally at a certain depth beneath the surface, they must always, before they are upraised and exposed at the surface, be of considerable antiquity, relatively to a large portion of the fossiliferous and volcanic rocks. They may be forming at all periods; but before any of them can become visible, they must be raised above the level of the sea, and some of the rocks which previously concealed them must have been removed by denudation. If the student will refer to the frontispiece, he will see that the strata A, which were the last deposited, are every where hidden from human observation by the sea, while the contemporaneous metamorphic rocks C are concealed at a still greater depth, as are also the plutonic rocks D of the same age. He will also observe that the strata C, which have recently become metamorphic,

are not parts of A, nor even of the groups immediately antecedent in date *a, b, c*, but they are portions of much older formations, *d, e, f, g, h, i*. Now, suppose that part of the earth's crust, which is represented in the frontispiece to be subjected, in various places, to a long series of upheaving and depressing movements; the beds A will, here and there, be partially upraised and converted into dry land, but the hypogene rocks C, D, although brought up nearer to the surface, will still, very probably, remain hidden from sight. Let a second period elapse and the rocks A may be raised in some countries to a height of several thousand feet; and still the rocks C and D may be almost every where hidden. During a third period, when the stratified formations A have been laid dry over large continental areas, and have reached the summits of some Alpine chains, the hypogene formations C D may also be forced up and exposed to view above the level of the ocean by similar causes; but they will rank no longer as modern rocks, because newer groups, both fossiliferous and volcanic, would have been formed subsequently to their origin. The student will also perceive how impossible it may then be to prove that the strata C became metamorphic at the period of the deposition of A, and how difficult not to exaggerate the antiquity of C as a series of metamorphic rocks, when the remote period of their

deposition has been ascertained, and the comparatively modern era of their crystallization remains uncertain.

Order of succession in metamorphic rocks. —

There is no universal and invariable order of superposition in metamorphic rocks, although a particular arrangement may prevail throughout countries of great extent, for the same reason that it is traceable in those sedimentary formations from which crystalline strata are derived. Thus, for example, we have seen that in the Apennines, near Carrara, the descending series, where it is metamorphic, consists of, 1st, saccharine marble ; 2dly, talcose-schist ; and 3dly, of quartz-rock and gneiss ; where unaltered, of, 1st, fossiliferous limestone ; 2dly, shale ; and 3dly, sandstone.

But if we investigate different mountain chains we find gneiss, mica-schist, hornblende-schist, chlorite-schist, hypogene limestone, and other rocks, succeeding each other, and alternating with each other, in every possible order. It is, indeed, more common to meet with some variety of clay-slate forming the uppermost member of a metamorphic series than any other rock ; but this fact by no means implies, as some have imagined, that all clay-slates were formed at the close of an imaginary period, when the deposition of the crystalline strata gave way to that of ordinary sedimentary deposits. Such clay-slates, in fact, are

variable in composition, and sometimes alternate with fossiliferous strata, so that they may be said to belong almost equally to the sedimentary and metamorphic order of rocks. It is probable that had they been subjected to more intense plutonic action, they would have been transformed into hornblende-schist, foliated chlorite-schist, scaly talcose-schist, mica-schist, or other more perfectly crystalline rocks, such as are usually associated with gneiss.

Uniformity of mineral character in Hypogene rocks.—Humboldt has emphatically remarked that when we pass to another hemisphere, we see new forms of animals and plants, and even new constellations in the heavens; but in the rocks we still recognize our old acquaintances,—the same granite, the same gneiss, the same micaceous schist, quartz-rock, and the rest. It is certainly true that there is a great and striking general resemblance in the principal kinds of hypogene rocks, although of very different ages and countries; but it has been shown that each of these are, in fact, geological families of rocks, and not definite mineral compounds. They are much more uniform in aspect than sedimentary strata, because these last are often composed of fragments varying greatly in form, size, and colour, and contain fossils of different shapes and mineral composition, and acquire a variety of tints from the mixture of various kinds of sediment. The materials

of such strata, if melted and made to crystallize, would be subject to chemical laws, simple and uniform in their action, the same in every climate, and wholly undisturbed by mechanical and organic causes.

Nevertheless, it would be a great error to assume that the hypogene rocks, considered as aggregates of simple minerals, are really more homogeneous in their composition than the several members of the sedimentary series. In the first place, different assemblages of hypogene rocks occur in different countries; and, secondly, in any one district, the rocks which pass under the same name are often extremely variable in their component ingredients, or at least in the proportions in which each of these are present. Thus, for example, gneiss and mica-schist, so abundant in the Grampians, are wanting in Cumberland, Wales, and Cornwall; in parts of the Swiss and Italian Alps, the gneiss and granite are talcose, and not micaceous, as in Scotland; hornblende prevails in the granite of Scotland—schorl in that of Cornwall—albite in the plutonic rocks of the Andes—common felspar in those of Europe. In one part of Scotland, the mica-schist is full of garnets; in another it is wholly devoid of them: while in South America, according to Mr. Darwin, it is the gneiss, and not the mica-schist, which is most commonly garnetiferous. And not only do the proportional quantities of

felspar, quartz, mica, hornblende, and other minerals, vary in hypogene rocks bearing the same name ; but what is still more important, the ingredients, as we have seen, of the same simple mineral are not always constant. (p. 191, and table, p. 210.)

The Metamorphic strata, why less calcareous than the fossiliferous.—It has been remarked, that the quantity of calcareous matter in metamorphic strata, or, indeed, in the hypogene formations generally, is far less than in fossiliferous deposits. Thus the crystalline schists of the Grampians in Scotland, consisting of gneiss, mica-schist, hornblende-schist, and other rocks, many thousands of yards in thickness, contain an exceedingly small proportion of interstratified calcareous beds, although these have been the objects of careful search for economical purposes. Yet limestone is not wanting in the Grampians, and it is associated sometimes with gneiss, sometimes with mica-schist, and in other places with other members of the metamorphic series. But where limestone occurs abundantly, as at Carrara, and in parts of the Alps, in connection with hypogene rocks, it usually forms one of the superior members of the crystalline group.

The scarcity, then, of carbonate of lime in the plutonic and metamorphic rocks generally, seems to be the result of some general cause.

So long as the hypogene rocks were believed to have originated antecedently to the creation of organic beings, it was easy to impute the absence of lime to the non-existence of those mollusca and zoophytes by which shells and corals are secreted ; but when we ascribe the crystalline formations to plutonic action, it is natural to inquire whether this action itself may not tend to expel carbonic acid and lime from the materials which it reduces to fusion or semi-fusion. Although we cannot descend into the subterranean regions where volcanic heat is developed, we can observe in regions of spent volcanos, such as Auvergne and Tuscany, hundreds of springs both cold and thermal, flowing out from granite and other rocks, and having their waters plentifully charged with carbonate of lime. The quantity of calcareous matter which these springs transfer, in the course of ages, from the lower parts of the earth's crust to the superior or newly formed parts of the same, must be considerable.*

If the quantity of siliceous and aluminous ingredients brought up by such springs were great, instead of being utterly insignificant, it might be contended that the mineral matter thus expelled implies simply the decomposition of ordinary subterranean rocks ; but the prodigious excess of car-

* See Principles, *Index*, "Calcareous Springs."

bonate of lime over every other element must, in the course of time, cause the crust of the earth below to be almost entirely deprived of its calcareous constituents, while we know that the same action imparts to newer deposits, ever forming in seas and lakes, an excess of carbonate of lime. Calcareous matter is poured into these lakes, and the ocean, by a thousand springs and rivers; so that part of almost every new calcareous rock chemically precipitated, and of many reefs of shelly and coralline stone, must be derived from mineral matter subtracted by plutonic agency, and driven up by gas and steam from fused and heated rocks in the bowels of the earth.

Not only carbonate of lime, but also free carbonic acid gas is given off plentifully from the soil and crevices of rocks in regions of active and spent volcanos, as near Naples, and in Auvergne. By this process, fossil shells or corals may often lose their carbonic acid, and the residual lime may enter into the composition of augite, hornblende, garnet, and other hypogene minerals. That the removal of the calcareous matter of fossil shells is of frequent occurrence, is proved by the fact of such organic remains being often replaced by silex or other minerals, and sometimes by the space once occupied by the fossil being left empty, or only marked by a faint impression. We ought not indeed to marvel at the general absence

of organic remains from the crystalline strata, when we bear in mind how often fossils are obliterated, wholly or in part, even in tertiary formations — how often vast masses of sandstone and shale, of different ages, and thousands of feet thick, are devoid of fossils — how certain strata may first have been deprived of a portion of their fossils when they became semi-crystalline, or assumed the *transition* state of Werner — and how the remaining organic remains have been effaced when they were rendered metamorphic. Some rocks of the last mentioned class, moreover, must have been exposed again and again to renewed plutonic action.

Concluding Remarks. — The theory of the origin of the hypogene or metamorphic strata, at a variety of successive periods, as expounded in this chapter, and still more the doctrine that such rocks may be now in the daily course of formation, has made and still makes its way, but slowly, into favour. The disinclination to embrace it has arisen partly from an inherent obscurity in the very nature of the evidence of plutonic action when developed on a great scale, at particular periods. It has also sprung, in some degree, from extrinsic considerations; many geologists having been unwilling to believe the

doctrine of the transmutation of fossiliferous into crystalline rocks, because they were desirous of finding proofs of a beginning, and of tracing back the history of our terraqueous system to times anterior to the creation of organic beings. But if these expectations have been disappointed, if we have found it impossible to assign a limit to that time throughout which it has pleased an Omnipotent and Eternal Being to manifest his creative power, we have at least succeeded beyond all hope in carrying back our researches to times antecedent to the existence of man. We can prove that man had a beginning, and that all the species now contemporary with man, and many others which preceded, had also a beginning, and that, consequently, the present state of the organic world has not gone on from all eternity, as some philosophers had maintained.

It can be shown that the earth's surface has been remodelled again and again; mountain chains have been raised or sunk; valleys formed, filled up, and then re-excavated; sea and land have changed places; yet throughout all these revolutions, and the consequent alterations of local and general climate, animal and vegetable life has been sustained. This has been accomplished without violation of the laws now governing the organic creation, by which limits are assigned to the variability of species.

The succession of living beings appears to have been continued not by the transmutation of species, but by the introduction into the earth from time to time of new plants and animals, and each assemblage of new species must have been admirably fitted for the new states of the globe as they arose, or they would not have increased and multiplied and endured for indefinite periods.*

Astronomy had been unable to establish the plurality of habitable worlds throughout space, however favourite a subject of conjecture and speculation; but geology, although it cannot prove that other planets are peopled with appropriate races of living beings, has demonstrated the truth of conclusions scarcely less wonderful, — the existence on our own planet of so many habitable surfaces, or worlds as they have been called, each distinct in time, and peopled with its peculiar races of aquatic and terrestrial beings.

The proofs now accumulated of the close analogy between extinct and recent species are such as to leave no doubt on the mind that the same harmony of parts and beauty of contrivance which we admire in the living creation, has equally characterized the organic world at remote periods. Thus as we increase our knowledge of

* See principles of Geol., Book 3.

the inexhaustible variety displayed in living nature, and admire the infinite wisdom and power which it displays, our admiration is multiplied by the reflection, that it is only the last of a great series of pre-existing creations, of which we cannot estimate the number or limit in times past.*

* See the author's Anniv. Address to the Geol. Soc. 1837. Proceedings of G. S., No. 49. p. 520.

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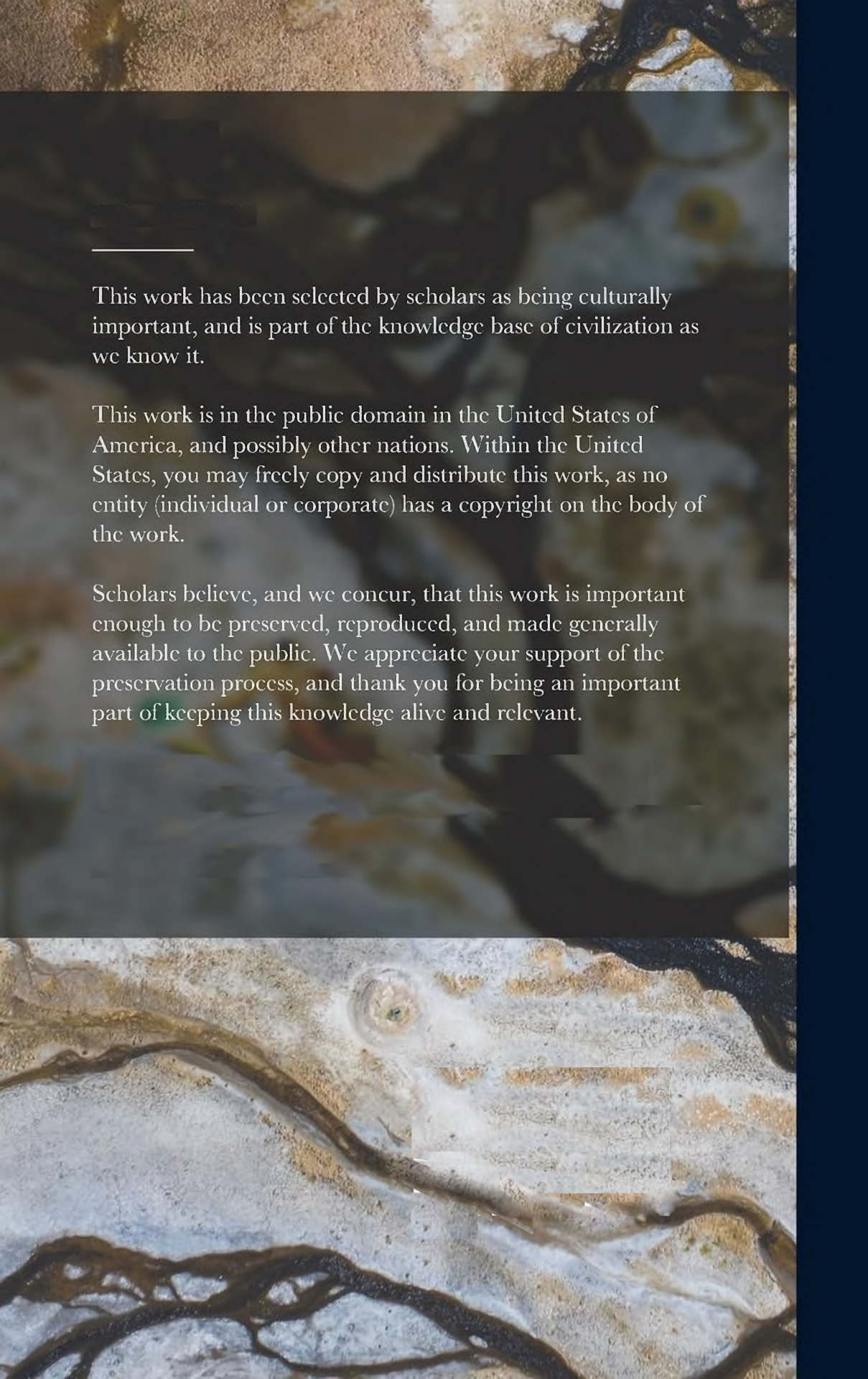
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